FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Asset Management Guide

Focusing on the Management of Our Transit Investments

OCTOBER 2012

FTA Report No. 0027
Federal Transit Administration

PREPARED BY
Dr. David Rose
Lauren Isaac
Keyur Shah
Tagan Blake
Parsons Brinckerhoff, Inc.

l Tran

COVER PHOTO

Courtesy of David Sailors

Asset Management Guide

Focusing on the Management of Our Transit Investments

OCTOBER 2012

FTA Report No. 0027

PREPARED BY

Dr. David Rose
Lauren Isaac
Keyur Shah
Tagan Blake

Parsons Brinckerhoff, Inc.
One Penn Plaza
New York, NY 11019

SPONSORED BY

Federal Transit Administration
Office of Research, Demonstration and Innovation
U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

AVAILABLE ONLINE

http://www.fta.dot.gov/research

Metric Conversion Table

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
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)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY	2. REPORT DATE October 2012	3. REPORT TYPE AND DATES COVERED June 2011 - September 2012

4. TITLE AND SUBTITLE Asset Management Guide: Focusing on the Management of Our Transit Investments	5. FUNDING NUMBERS FTA-2011-002-TRI
6. AUTHOR(S) Dr. David Rose, Lauren Isaac, Keyur Shah, Tagan Blake	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(ES) Parsons Brinckerhoff, Inc. One Penn Plaza New York, NY 11019	8. PERFORMING ORGANIZATION REPORT NUMBER FTA Report No. 0027
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Transit Administration East Building 1200 New Jersey Avenue, SE Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER FTA Report No. 0027

11. SUPPLEMENTARY NOTES
http://www.fta.dot.gov/research

12A. DISTRIBUTION/AVAILABILITY STATEMENT Available from: National Technical Information Service (NTIS), Springfield, VA 22161 Phone 703.605.6000, Fax 703.605.6900, email [orders@ntis.gov]	12B. DISTRIBUTION CODE TRI-20

13. ABSTRACT

To advance transit asset management, this guide provides a transit-specific asset management framework for managing assets individually and as a portfolio of assets that comprise an integrated system. The guide provides flexible, yet targeted guidance to advance the practice and implementation of transit asset management.

Objectives:

- Explain what transit asset management is and what the business benefits to an agency are.
- Provide an enterprise asset management framework and business model that agencies can refer to as "best practice."
- Describe the elements of transit asset management plan.
- Detail, for each major asset class, the major enabling components of asset management: inventory, condition assessment, performance analysis and modeling, risk management, and lifecycle cost management.
- Guide organizations through the migration from their current baseline to high-performance asset management.

14. SUBJECT TERMS Transit Asset Management, Asset Management Guide	15. NUMBER OF PAGES 268

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT None

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

This guide could not have been developed without the invaluable input from many colleagues and friends throughout the transit industry. Special thanks go to the following members of our Agency Review Team:

Steve Berrang, New York Metropolitan Transportation Authority
Rolando Cruz, Long Beach Transit
Paul Edwards, Utah Transit Authority
Rick Kindig, TriMet
Brian McCartan, Sound Transit
Frank Ruffa, Bay Area Rapid Transit District
Jerry Rutlege, King County Transit
David Springstead, Metropolitan Atlanta Rapid Transit Authority
Laura Zale, Southeastern Pennsylvania Transportation Authority

In addition to the review team, we received assistance from:

Tamar Allen and John McCormick, Bay Area Rapid Transit District
Jacob Balter, Long Island Rail Road
Michelle Caldwell, Los Angeles County Metropolitan Transportation Authority
Grace Gallucci, formerly of Chicago Regional Transportation Authority
Rhonda Jalbert, Valley Regional Transit
Steve Johnstone, Santa Clara Valley Transportation Authority
Kris Miller, Fairfax Connector
Leah Mooney, Chicago Transit Authority
Richard Moore, London Underground
Victor Rivas and Eric Waaramaa, Massachusetts Bay Transportation Authority
Tom Sargant, Victoria Department of Transportation
Glen Tepke, Metropolitan Transportation Commission

We are also grateful to the following people for their assistance in developing the case studies:

William Robert, Spy Pond Partners
Kat Lawrence, Spy Pond Partners

PREFACE

For some time, the Federal Transit Administration (FTA) and the U.S. transit industry having been working to improve the understanding and practice of transit asset management. There is considerable evidence that this is a critical area of focus. Improving transit asset management is now a national policy. In its 2010 National State of Good Repair Assessment, FTA found that more than 40 percent of bus assets and 25 percent of rail transit assets were in marginal or poor condition. There is an estimated backlog of $50 to $80 billion in deferred maintenance and replacement needs, of which the vast majority is rail related. The enactment of Moving Ahead for Progress in the 21st Century (MAP-21) places the requirement on transit agencies to prepare a Transit Asset Management Plan. Transit agency customers, policy-makers, and public agencies are holding agency management accountable for performance and increasingly expect more business-like management practices. The magnitude of these capital needs, performance expectations, and increased accountability requires agency managers to become better asset managers.

To advance transit asset management, this guide provides a transit-specific asset management framework for managing assets individually and as a portfolio of assets that comprise an integrated system. The guide provides flexible, yet targeted guidance to advance the practice and implementation of transit asset management.

To accomplish this, the guide:

- Explains what transit asset management is and what the business benefits to an agency are.
- Provides an enterprise asset management framework and business model that agencies can refer to as "best practice."
- Describes the elements of transit asset management plan.
- Details, for each major asset class, the major enabling components of asset management: inventory, condition assessment, performance analysis and modeling, risk management, and lifecycle cost management.
- Guides organizations through the migration from their current baseline to high-performance asset management.

This guide makes accessible lessons-learned from those with "hands-on" experience with each asset class, and positions transit agencies to jump start the cultural change from a "find and fix approach" to maintenance/asset management to a "predict and prevent" approach that reduces cost and improves safety and reliability. This guide includes examples and practices that agencies can apply; it is intended to provide guidance for a transit agency interested in improving their asset management awareness and maturity. This guide is not an FTA requirement.

SECTION
1

This section outlines the purpose, structure, and sources of this document. Additionally, it helps the reader navigate to the sections most useful to them.

Introduction

This guide is designed to increase the awareness and improve the practice of asset management in the transit industry in the United States. It provides a transit agency-specific application of asset management concepts, processes, and tools. The purpose is to support an agency's drive to increase the maturity of asset management practice and to provide tools and resources for agency managers and practitioners across the country.

In its 2010 *National State of Good Repair Assessment*, the Federal Transit Administration (FTA) found that more than 40 percent of bus assets and 25 percent of rail transit assets are in marginal or poor condition. There is an estimated backlog of $50–$80 billion in deferred maintenance and replacement needs, of which the vast majority is rail-related. Transit agency customers, policy-makers, and public agencies are holding agency management accountable for performance and increasingly expect more business-like management practices. The magnitude of these capital needs, performance expectations, and increased accountability requires agency managers to become better asset managers.

Asset management is a cornerstone for effective performance management. By leveraging data to improve investment decision-making, asset management improves reliability, safety, cost management, and customer service.

Objectives of This Guide

The guide can be used as a resource for agency managers to develop the management practices, tools, and procedures needed to improve investment decisions throughout their organization. This guide has the following objectives:

- Introduce key asset management concepts.
- Present an asset management framework and business model that define and communicate "best practice."
- Provide guidance that can be used for assessing and advancing asset management maturity within any agency.
- Include tools and case studies that can support implementation.

A Guide Developed for the Transit Industry

The building blocks for this transit asset management guide incorporate relevant concepts from existing asset management guides, analysis of transit agency best practices, and the application of asset management practices to the transit industry, as depicted in Figure 1-1.

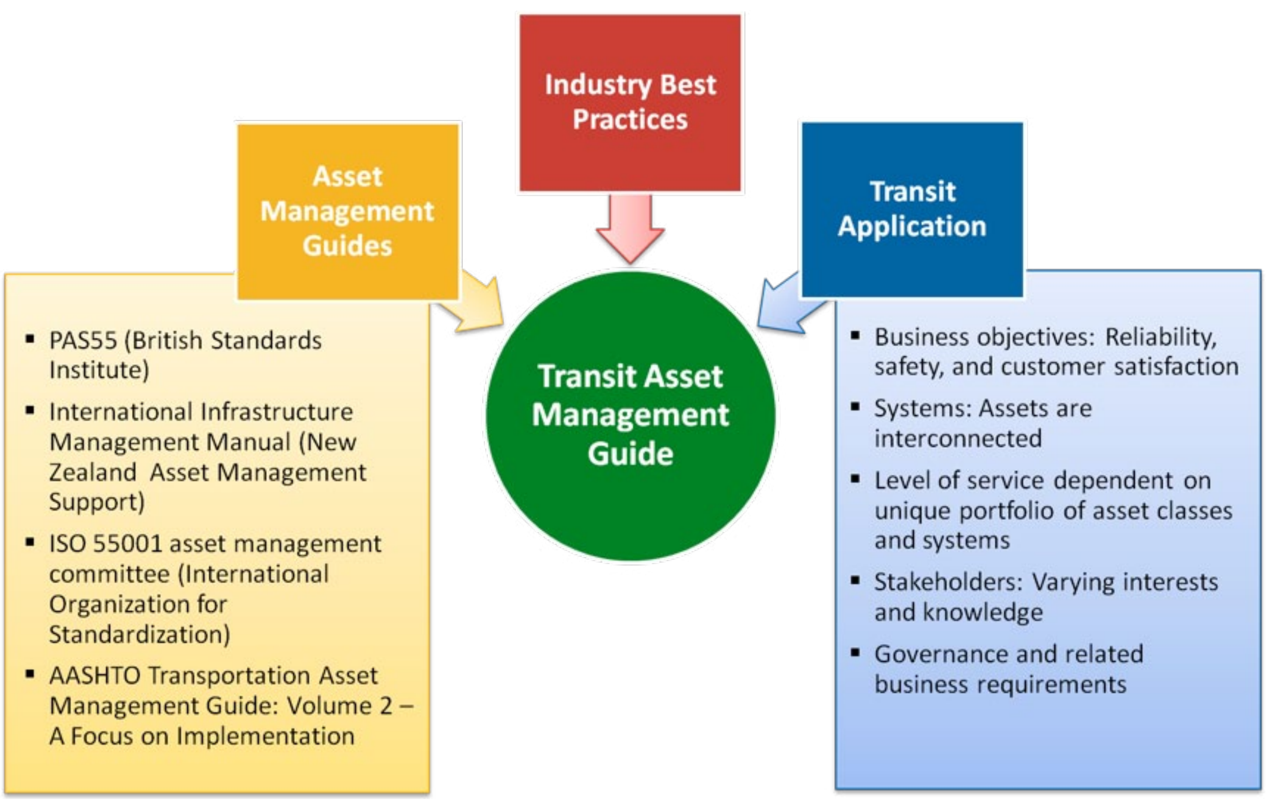


Figure 1-1 *Guide Building Blocks*

There is a significant body of asset management knowledge and broad standards of practice for the infrastructure industry. These include the following:

- **PAS55** is the "publicly available specification" for the optimized management of physical assets published by the British Standards Institute.
- ***International Infrastructure Management Manual*** is an asset management guide for the public works industry developed by the New Zealand Asset Management Support (NAMS) group.
- **ISO 55001**—newly created in 2010—is the International Organization for Standardization (ISO)-approved project committee (PC251) to deliver an Asset Management Standard for Asset Management. Currently, drafts are being circulated.
- ***American Association of State Highway and Transportation Officials (AASHTO) Transportation Asset Management Guide – A Focus on Implementation*** provides a framework for addressing highway asset management. It includes two volumes of asset management principles that provide implementation guidance for advancing the state of the U.S. highway industry's asset management practices.

The asset management guides described above originated in work done to address large-scale long-life fixed infrastructure. Our intent in this guide is to address the application of asset management across the transit portfolio of assets, which includes assets with a range of useful lives, replacement costs, and inter-relationships.

This guide applies and adapts these documents to address the requirements for successful asset management in the transit industry. Unlike many other infrastructure sectors, the transit industry manages a highly complex and diverse portfolio of assets that is required to function as a system. For example, for a passenger rail service to run, the track, communication systems, rail vehicle, and stations must all be working together effectively. Many of the transit industry's assets are customer-facing, and the asset types managed by different U.S. transit agencies are highly variable because of significant variations in geography, weather, ridership, procurement practices, and regulatory requirements. As such, this guide incorporates relevant concepts from the existing research with a focus on what can be applied to U.S. transit agencies. To demonstrate its applicability, best practices from around the world are incorporated into the guide (see Figure 1-1). A full listing of research and document sources is available in the Glossary.

Transit Agency Collaboration

This guide reflects input from transit agency managers from across the U.S. Throughout the development of this guide, the Parsons Brinckerhoff team presented drafts at a variety of forums, including American Public Transportation

Association (APTA) and Transportation Research Board (TRB) conferences and the APTA State of Good Repair Standards group, the FTA State of Good Repair Roundtables, and the FTA State of Good Repair Working Group. The purpose was to seek feedback in addition to increase awareness regarding the state of the industry's asset management practices. Many of these sessions involved compiling and sharing best practice examples, discussing the appropriate presentation of material, and brainstorming about how to address common industry challenges associated with asset management.

The Parsons Brinckerhoff team is grateful to the many transit agency managers that spent their time providing substantive input and who reviewed draft material. Their input and collaboration have made this a more valuable document.

Sections Overview

The following describes the objectives and contents of each section and the *Asset Management Guide Supplement*:

- **Section 2: Introducing Transit Asset Management** – This section defines asset management for the transit industry, including which assets are included, how asset management fits into an agency's other management processes, and what business processes are included. The section outlines the challenges the industry faces and the benefits of improving an agency's asset management maturity. This section also provides "visuals" of a highly functioning asset management transit agency.
- **Section 3: Asset Management Framework Business Processes** – For each business process outlined in the asset management framework, an overview of "best practice" and how it fits into the broader asset management framework is included; key implementation activities and challenges and peer examples are also included. These business processes comprise the development and management of the asset management policy, strategy, plan, inventory, condition assessment and performance monitoring, lifecycle management plan, capital programming, operations and maintenance budgeting, and performance modeling. A reader will understand all the components of asset management, including how to improve them independently and how they work together.
- **Section 4: Asset Management Information Systems** – This section describes the industry's current information systems environment, components of an asset management information system, and implementation principles. This section also provides a "visual" of a high-functioning asset management information system.
- **Section 5: Implementation Guidance** – This section provides guidance for assessing an agency's current state of asset management maturity and then outlines potential implementation paths and change management

considerations for how to advance from its current state towards "best practice" while considering the unique needs of that agency. To support implementation, accompanying this guide is a *Transit Asset Management Maturity Agency Self-Assessment Tool* (see Appendix B).

- **Asset Management Guide Supplement** – This document (see Appendix A) identifies the fundamentals that should be considered in the lifecycle management of each asset class and provides information to support the development of an agency's asset class-specific lifecycle management plan(s), including industry standards and lifecycle management principles associated with each asset class. The document identifies the building blocks from which an agency can consider the maturity of its practices and strengthen asset management for each asset class.

How to Use this Guide

The following provides an overview of which sections are likely to be of most interest to different categories of readers. Readers are intended to be managers and staff from all levels of an agency or external stakeholders.

The following list suggests how different people may approach reading this guide:

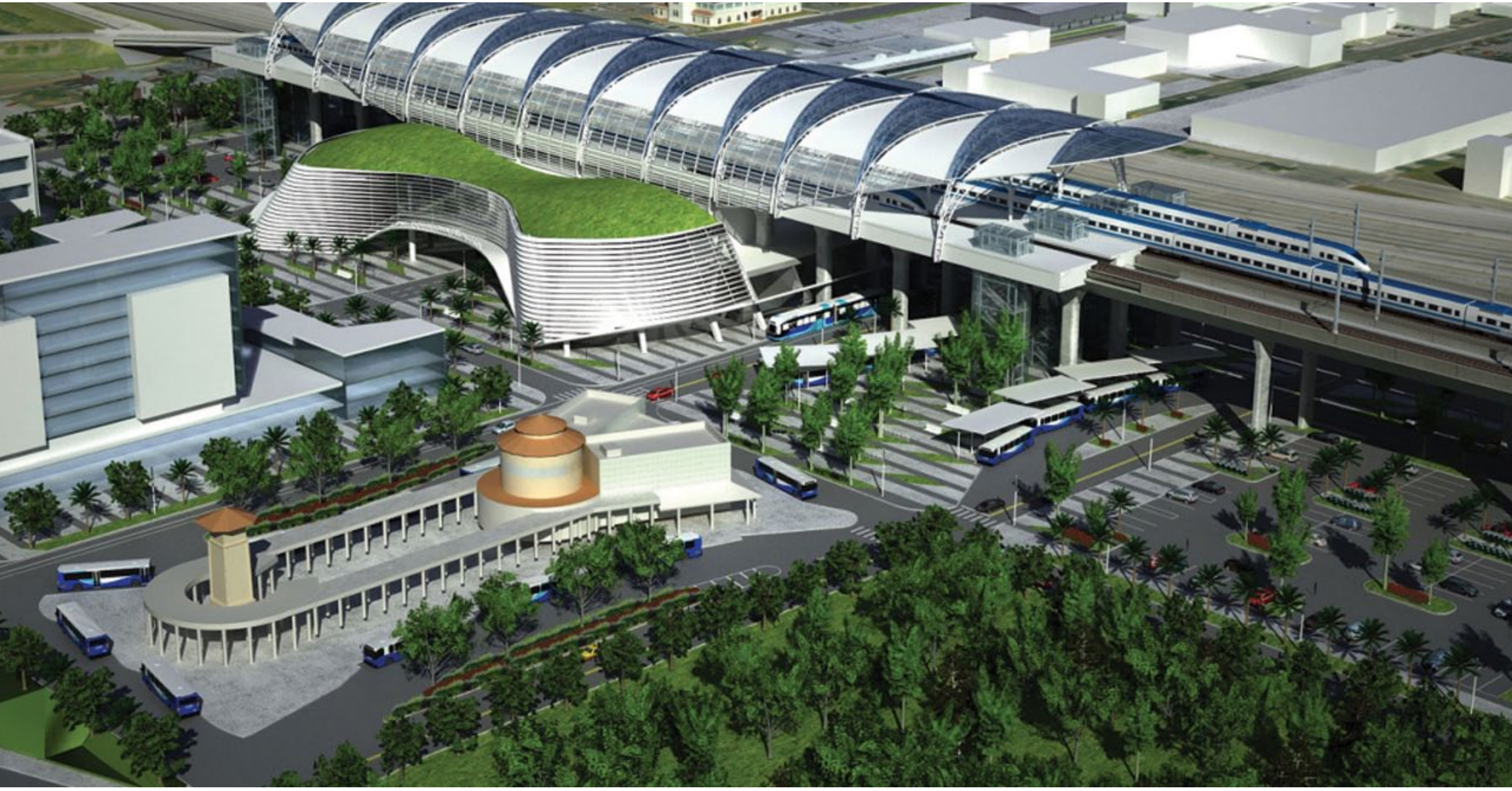
- **Agency Executives** – This group may be interested in understanding the key asset management concepts (Section 2) and how it is integrated within the agency's business processes (Section 3). They also may be interested in understanding their agency's current asset management maturity and how to improve it (Section 5).
- **Asset Management Program Manager** – This person is intended to lead the agency's asset management initiative, including leading the development of the agency's asset management plan, communicating to all stakeholders, and providing the necessary accountability. To be most effective in this position, the Asset Management Program Manager should probably read all sections of this guide, with a significant focus on implementation guidance (Section 5).
- **Agency Management and Staff** – When fully implemented, asset management could affect managers and staff at all levels and in all departments of an agency. For that reason, agency management and staff should understand what asset management is (Section 2) and how it is integrated within the agency's business processes (Section 3).
- **Agency "Asset Owners"** – This term refers to the agency managers who are responsible for "owning" an asset class (for example, railcar vehicles, stations, and communication systems) throughout their lifecycle. The asset owners are intended to develop lifecycle management plans for their respective asset class. To support this effort, asset owners may want to focus on the section on lifecycle management planning (Section 3) and the respective asset class section (*Asset Management Guide Supplement*).

- **Transit Consultants and Contractors** – Depending on their interests, transit consultants and contractors should be interested in many of the sections. Suppliers may be interested in understanding the general requirements of asset management (Section 2) or the lifecycle management of specific asset classes (*Asset Management Guide Supplement*). Consultants supporting the development of an asset management plan and implementation strategy may be interested in the asset management business processes (Section 3) and the implementation guidance (Section 5). Information systems vendors may be interested in understanding the functional requirements of asset management information systems (Section 4). Change management consultants may be most interested in the implementation requirements (Section 5).
- **External Stakeholders** – External stakeholders may include oversight bodies (including metropolitan planning organizations), elected officials, and industry research groups. These stakeholders will likely be interested in the outcomes (reliability, efficiency, safety, accountability) associated with improved asset management, so they may be interested in a general introduction to asset management, including its potential outcomes (Section 2), an overview of the asset management plan (Section 3), and implementation requirements (Section 5).

Table 1-1 summarizes which sections are likely to be of the most interest to different categories of readers.

Table 1-1 *How to Use This Guide*

	Section 1	Section 2	Section 3	Section 4	Section 5	Supplement
Agency Executives	X	X	X		X	
Asset Management Program Manager	X	X	X	X	X	X
Agency Management and Staff	X	X	X		X	
Agency "Asset Owners"	X		X		X	X
Transit Consultants and Contractors	X	X	X	X	X	X
External Stakeholders	X	X	X	X	X	



Source: Florida Department of Transportation

SECTION
2

This section defines asset management for the transit industry, classifies transit assets, and describes the key business processes and how they can be embedded into an agency's management processes. It outlines today's asset management challenges and the benefits of improving an agency's asset management maturity. This chapter also provides the reader with a "visual" of a highly functioning asset management transit agency.

Introducing Transit Asset Management

This guide provides the following definition:

> Transit asset management is a strategic and systematic process through which an organization procures, operates, maintains, rehabilitates, and replaces transit assets to manage their performance, risks, and costs over their lifecycle to provide safe, cost-effective, and reliable service to current and future customers.

Figure 2-1 shows how asset management processes are ongoing and involve evaluating and managing the relationships between costs, risks, and performance over the asset's lifecycle. Asset management addresses the following two concepts:

1. **Customer Level of Service** – Asset management can affect level of service by improving on-time performance and vehicle cleanliness, and by reducing missed trips, slow orders, and service and station shutdowns. It can also improve safety, security, and risk management. Asset management provides accountability and communicates performance and asset condition to customers.

2. **Lifecycle Management** – The core of asset management is understanding and minimizing the total cost of ownership of an asset while still maximizing its performance. Transit asset management integrates activities across departments and offices in a transit agency to optimize resource allocation by providing quality information and well-defined business objectives to support decision making within and between classes of assets.

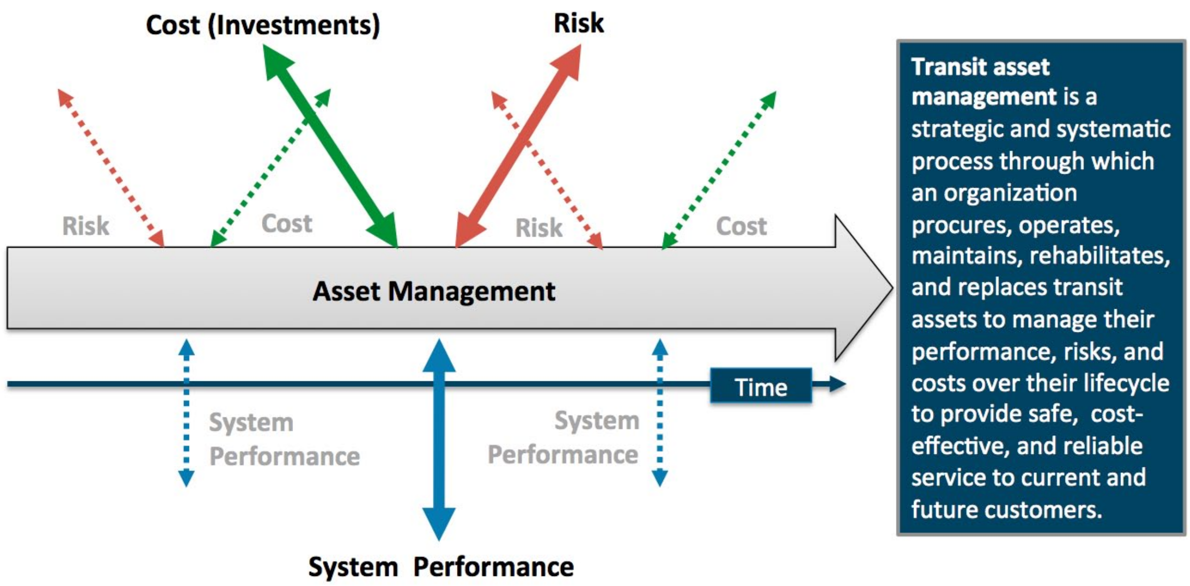


Figure 2-1 *Asset Management Defined*

Customer level-of-service and lifecycle management are addressed at the enterprise level and for each class of assets. Enterprise level refers to management or decision-making activities that occur at the higher levels of an organization and apply across the entire organization (for example, capital funding allocations). Asset class-level activities, on the other hand, refer to the management activities that are associated with a particular asset class (for example, vehicles, stations, systems). See Table 2-1 for examples.

Table 2-1 *Asset Management at the Enterprise and Asset Class Levels*

	Enterprise Level	Asset Class Level
Customer Level of Service	Establish, measure, and manage customers' level of service by using metrics like on-time performance, number of safety incidents, and overall customer satisfaction.	Measure and manage how individual assets perform using customer level of service metrics. Examples include measuring a railcar's mean time between failure or a station's cleanliness.
Lifecycle Management	Use accurate and consistent information about assets, current conditions, and level of service to allocate resources and maximize performance.	Understand and minimize the total cost of ownership of an asset while maximizing its performance. Produce a lifecycle management plan for each asset.

These concepts are further discussed in the Glossary.

Asset Management Benefits

Through asset management, transit agencies can more effectively use available funds to improve the physical condition and performance of their system. This, in turn, has the potential to increase ridership. Table 2-2 highlights some of the benefits associated with improved asset management activities.

Table 2-2

Transit Asset Management Benefits

Transit Agency Business Benefits	Asset Management Approach
Improved customer service	• Improves on-time performance and service operations, vehicle and facility cleanliness; reduces missed trips, slow orders, and station shutdowns • Focuses investments around customer-centered goals and metrics
Improved productivity and reduced costs	• Maintains assets more effectively, using condition-based approaches and using predictive and preventive maintenance strategies (where these can be employed) to reduce costs while improving service delivery
Optimized resource allocation	• Better aligns spending with an agency's goals and objectives to obtain the greatest return from limited funds • Incorporates lifecycle cost, risk, and performance trade-offs into capital programming and operations & maintenance budgeting
Improved stakeholder communications	• Provides stakeholders with more accurate and timely customer-centered performance indicators • Provides tools to communicate forecasted performance metrics (including level of service) based on different levels of funding

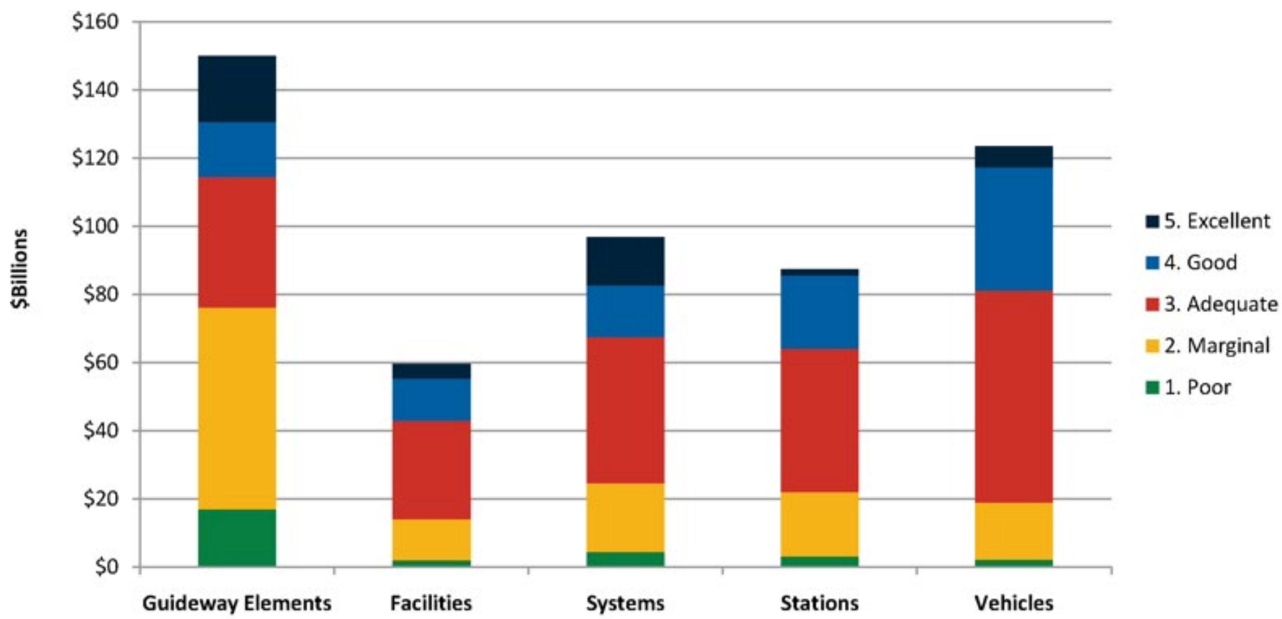
The Transit Asset Management Challenge

The Overall State of Transit Assets

In its 2010 *National State of Good Repair Assessment*, FTA found that one-third of the nation's transit assets are at or have exceeded their expected useful life. More than 40 percent of bus assets and 25 percent of rail transit assets are in marginal or poor condition. The level of capital investment required to attain a state of good repair[1] in the nation's transit assets is projected to be $77.7 billion.[2] In other words, a "lump sum" investment of roughly $77.7 billion would be required for the immediate replacement of all assets that currently exceed their useful life (see Figure 2-2). Transit assets exceeding their useful life can result in asset failures, which can increase the risk of catastrophic accidents, disrupt service, and strain maintenance departments.

[1] State of good repair was defined using the FTA's numerically-based system for evaluating transit asset conditions: 5 (excellent), 4 (good), 3 (adequate), 2 (marginal), 1 (poor). This study considered an asset to be in a state of good repair when the physical condition of that asset was at or above 2.5.

[2] *National State of Good Repair Assessment*, FTA, 2010, p. 19.



Source: *National State of Good Repair Assessment*. FTA, 2010, p. 15.

Figure 2-2 *2010 Transit Asset Conditions*

Asset Management is Critical for the Nation's Growing Transit Asset Inventory

Our investment in transit assets continues to grow—increasing the importance of efficient and fiscally-responsible management of assets. Between 1992 and 2010, the number of vehicles in the nation's transit fleets increased by 63 percent (Figure 2-3). Over the past 10 years, almost universally, the average age of transit fleets has decreased or remained the same; however, this is not a result of better asset management. The average vehicle age has decreased mainly because new vehicles have been added to the fleets, while older vehicles were kept in service.

As shown in Figure 2-4, the largest backlog of state-of-good-repair needs is due to heavy rail assets. Commuter rail and buses are comparable in the size of their backlogs. These categories are discussed in the following sections.

Light Rail Vehicle Fleets are Growing; Agencies are Now Managing Fleets of Different Ages

In June 2010, the level of capital investment required to attain and maintain a state of good repair for light rail transit assets was estimated to be $3.6 billion. The newer systems like San Diego and Portland are now more than 20 years old, and the initial vehicle fleets are approaching or exceeding their useful lives. Nationally, the number of light rail transit systems and the size of the light rail fleet almost doubled between 1992 and 2010. During this time, the oldest vehicles remained in use while the new assets were being added to the fleet. This has created a mixed-aged fleet with vehicles at many different stages of their useful lives, sometimes being operated by the same agencies.[3]

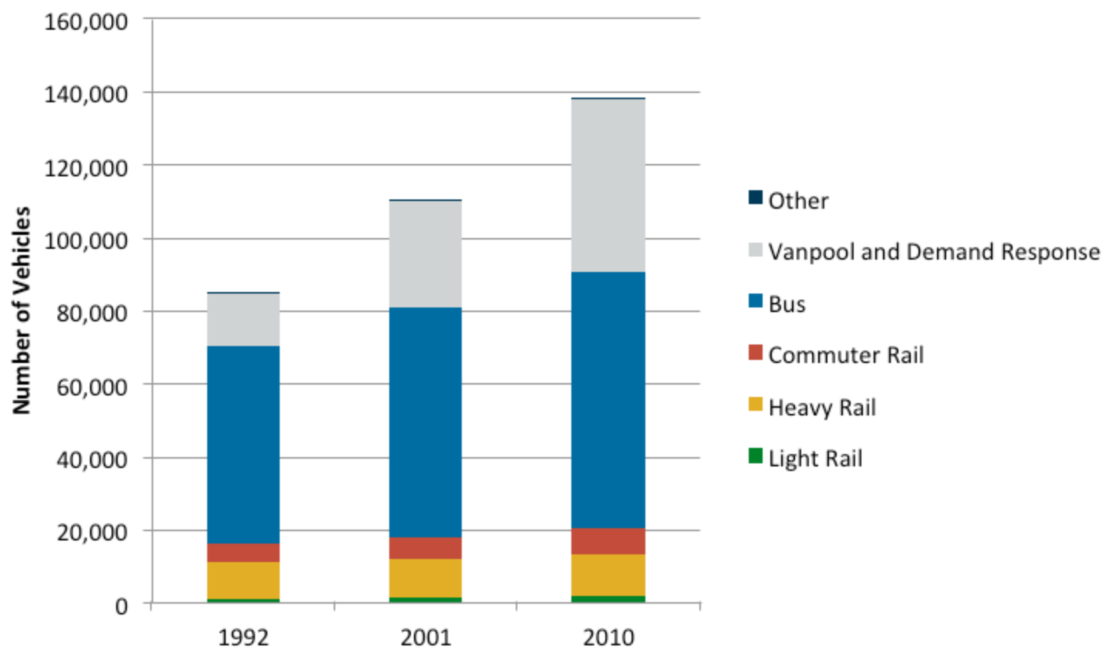


Figure 2-3 *Growth in Number of Vehicles in Transit Fleet*

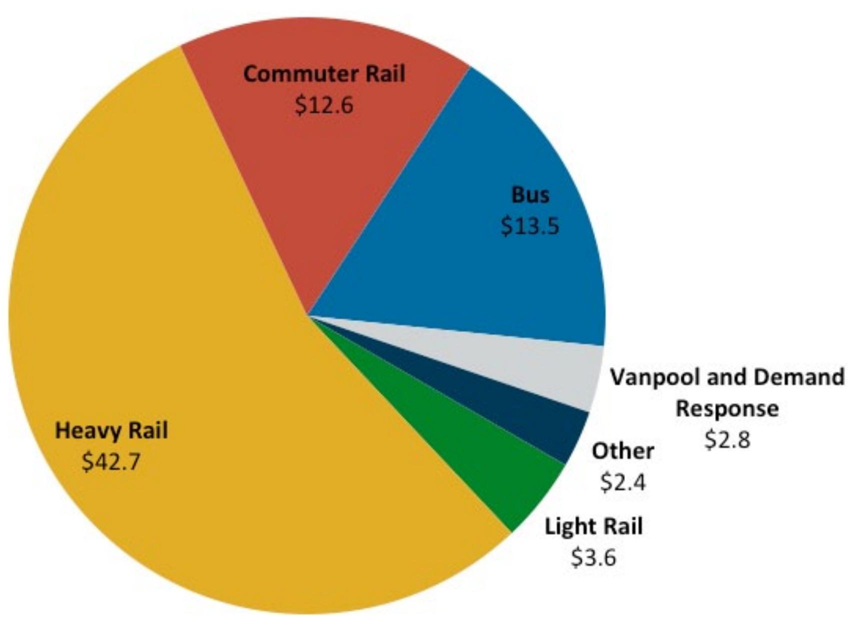


Figure 2-4 *Current (2010) Backlog of State of Good Repair Needs (shown in billions of 2009 $)*[4]

[3] National Transit Database, FTA. Accessed December 30, 2011. *http://www.ntdprogram.gov/ntdprogram.*

[4] *National State of Good Repair Assessment*, Federal Transit Administration, 2010, p. 19.

Heavy Rail Transit Assets are Being Used Longer Without Replacement

As of June 2010, the level of capital investment required to attain and maintain a state of good repair for heavy rail assets was projected to be $42.7 billion. The number and types of systems have remained mostly the same while the average age of transit assets has gone up and down with large procurements of new vehicles by some agencies and few replacements by others. Because of the relatively longer in-service lives of heavy rail vehicles, procurement of new vehicles is infrequent, which has a significant impact on the overall age of the fleet. For example, in 2010 the average age of the assets on the two oldest systems was 36 and 39 years, respectively, meaning that these two systems will likely need to replace a substantial part of their fleets in the near future. Some systems' fleets have aged between 1992 and 2010 with no expansion or replenishment of new vehicles.

Commuter Rail Systems and Assets Have Grown, Yet Conditions Have Remained Constant

Between 1992 and 2010, commuter rail systems grew by 33 percent, which means there was a significant growth in the number of commuter rail vehicles. The average age of commuter rail assets has fluctuated in that time but remained relatively the same as many of the systems have added new vehicles. As of June 2010, the level of capital investment required to attain and maintain a state of good repair for commuter rail assets was projected to be $12.6 billion.

Quantity of Bus Assets is Growing and Average Retirement Age is Later than Intended

The average age of buses decreased from 8.1 years in 1992 to 7.4 years in 2010. Over the same time, the number of buses and transit systems grew by 25 percent. In its *Useful Life of Transit Buses and Vans* (2007), FTA examined the optimal lifecycle for buses against how the bus fleet was actually being used. The study found that the average retirement age of 12-year/500,000-mile buses was 15.1 years—3 years past the expected retirement age. Seventy-five percent of vehicles are 14 years or older when they are retired. The maintenance cost for vehicles beyond their recommended life is, on average, between 10 and 50 percent higher. The level of capital investment required to attain a state of good repair for bus assets was estimated to be $13.5 billion.

Vanpool and Demand Response Operators and Assets have more than Doubled

Between 1992 (when transit agencies were just beginning to implement new or modify existing paratransit systems to meet the requirements of the Americans with Disabilities Act) and 2010, the number of vanpool and direct-response operators grew by 50 percent. Meanwhile, the number of assets in the fleet grew by 300 percent. This has been the fastest growth among any of the modes, showing the evolution of transit offerings over time. The backlog in maintenance was projected to be $2.8 billion.

All modes of transit require continued asset management because of the direct link between age, condition, and maintenance costs of vehicles. As the number of agencies and the size of the fleet continue to increase, lifecycle asset management will be integral to cost-effectively maintaining the quality of public transit in the country. All transit agencies own assets and manage them, so they practice asset management in some fashion.

Transit Assets Defined

Transit assets include both fixed long-life infrastructure assets (including, for example, structures, tunnels, facilities, and maintenance of way) and equipment (that is, bus, rail, and paratransit rolling stock). This guide provides a transit-specific asset management framework for managing assets individually and as a portfolio of assets that comprise an integrated system. In this guide, transit assets include physical infrastructure elements, equipment, and systems. Our definition of assets does not include "human capital" (the skills, training, goodwill and institutional memory of employees), financial assets, data/information, or intangible assets (for example, reputation, culture, and intellectual property). This guide also does not address roadway, park-and-rides, or administrative offices or other buildings whose lifecycle management requirements are not unique to the transit industry. It also does not include ferry or other maritime assets.

Figure 2-5 provides the asset hierarchy used in this guide and provides a starting point to organize transit assets by broad asset categories (or groupings of asset classes, including vehicles and systems) and asset classes (or groupings of items with comparable asset management requirements, including track and signals).

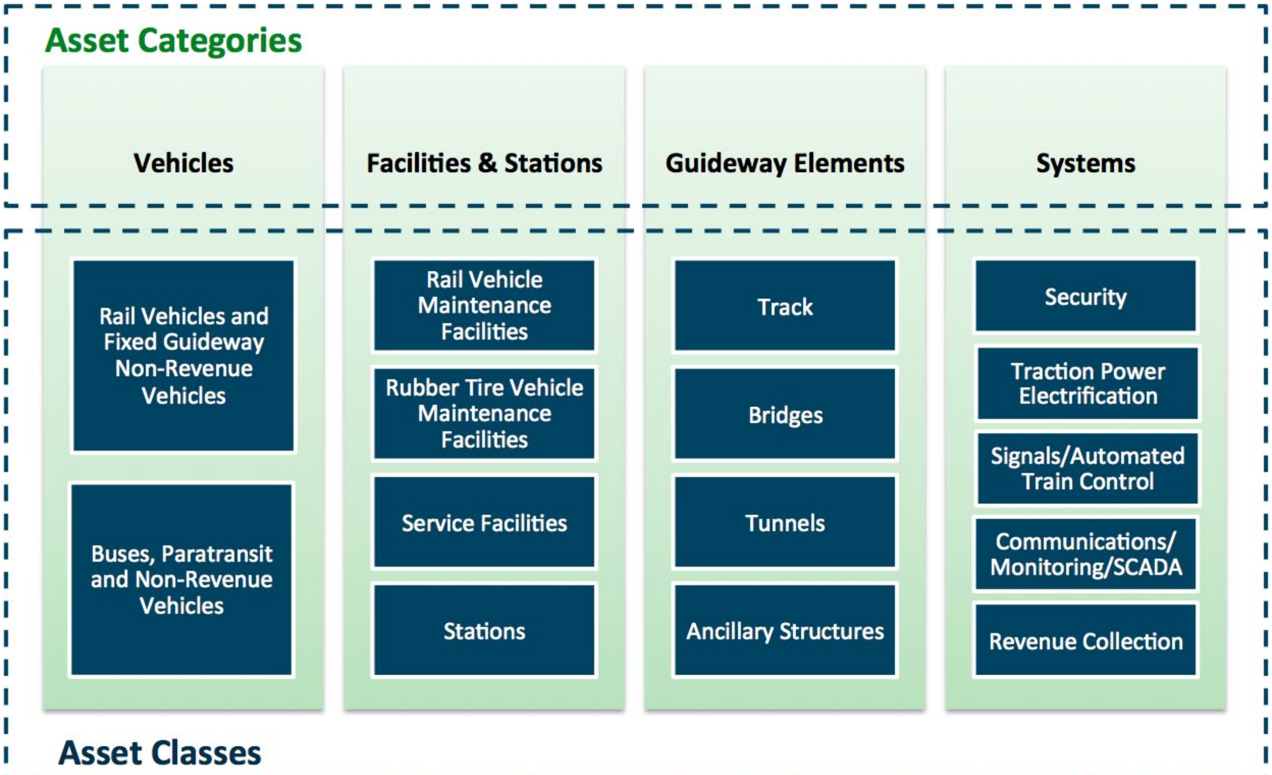


Figure 2-5 *Transit Asset Categories and Classes*

Section 5 provides best practice guidance for the management of each of the asset classes, including peer examples.

Asset Management in Context

Asset management is an integral part of the business management of a transit agency. In a highly performing transit agency, asset management is a core strategic management process, along with risk management and performance management. Together, these are agency-wide management processes that support the accomplishment of the entire agency's goals and objectives. None of the processes can be entirely effective without the others (Figure 2-6).

Asset management is most successful when it is integrated into an agency's existing management processes for establishing policy, strategy, and business plans, as well as connected to an agency's performance management and risk management processes. An agency's strategic plan is the starting point for developing asset management policy, strategy, and plan because the strategic plan provides the vision, mission, and values of the organization along with organizational goals, policies, and strategies. To be most effective, transit asset management activities should be integrated into existing strategic, business, and operational management processes.

Figure 2-6

Components of Agency Strategic Management

Asset management supports and enables the following elements of transit agency management:

- ***Performance management focus***: Asset management integrates management activities across the agency's various functional areas to address customer level of service and performance outcomes.
- ***Optimization of resources***: Asset management aligns investment decisions associated with operations and maintenance budgeting and capital programming to achieve levels of service that meet agency goals.
- ***Fact-based management***: Asset management is data driven and transparent.
- ***Performance culture***: Asset management is outcome based, establishes metric driven management, and provides tools to adopt a "predict and prevent" or "reliability" culture as opposed to a "find and fix" culture.

Transit Asset Management Framework

The asset management framework in Figure 2-7 offers a starting point from which to apply asset management concepts and implement the principles, processes, and practices depicted.

Asset Management Business Processes

The asset management framework depicts a complex set of business processes. The following sections and Figure 2-8 introduce each of the three categories of business processes necessary to fully realize the benefits of asset management:

- Vision and Direction
- Lifecycle Management
- Cross-Asset Planning and Management

Detailed definitions, implementation guidance, and examples for each of these business processes can be found in Section 3. A brief introduction to the three categories of business processes is described below.

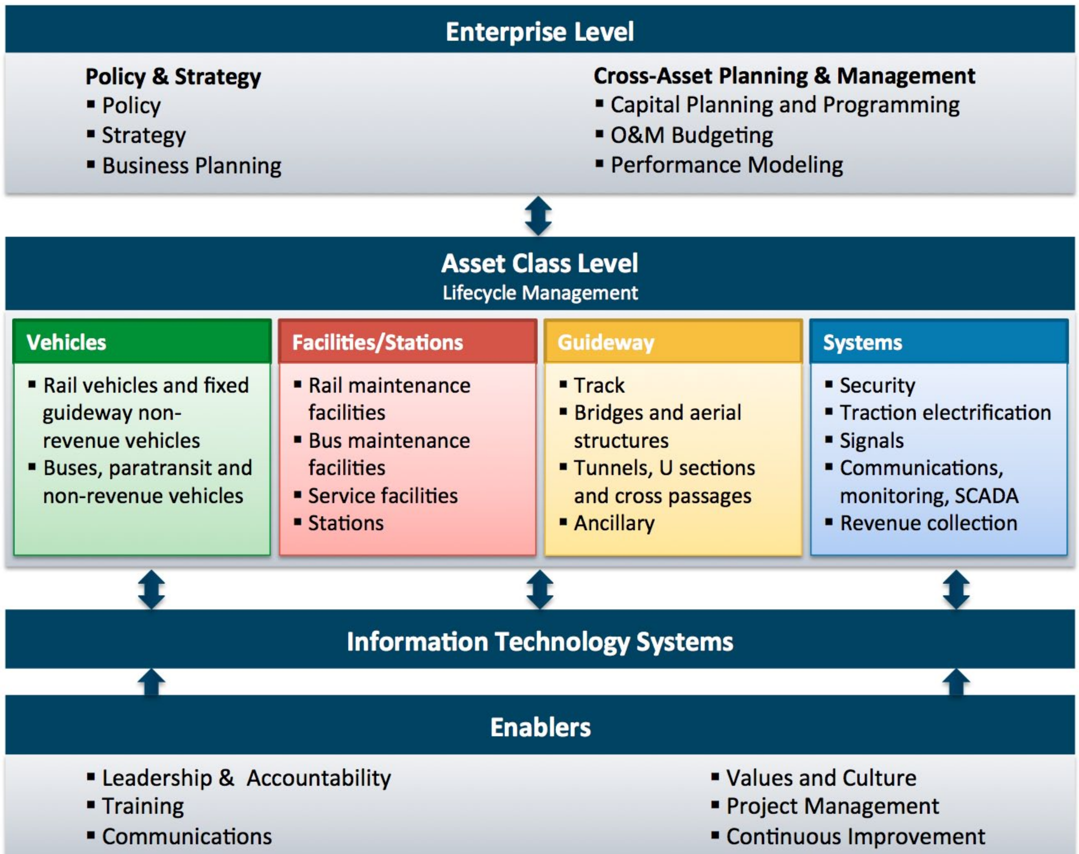


Figure 2-7 *Asset Management Framework*

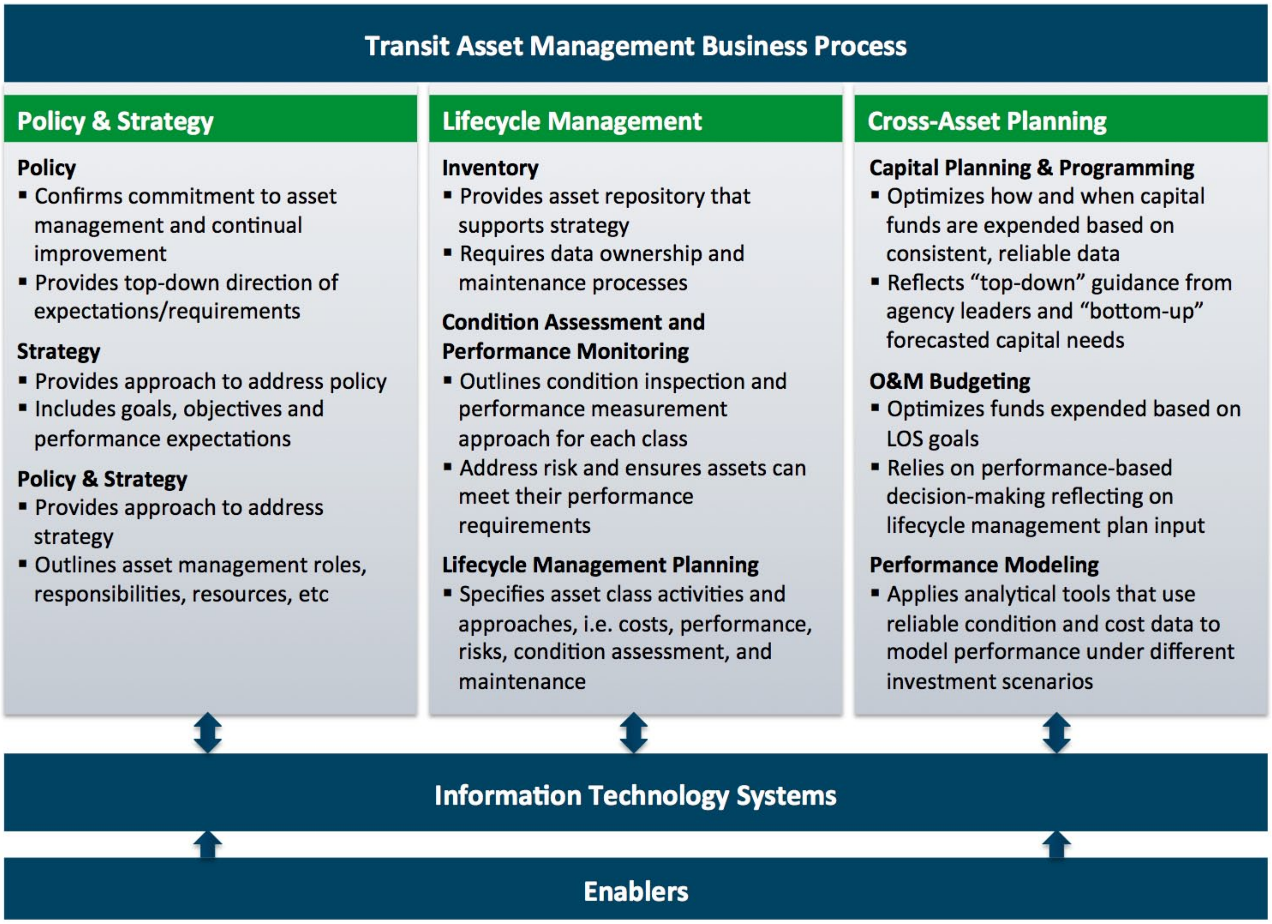


Figure 2-8 *Transit Asset Management Business Processes*

Vision and Direction

An agency's existing policy and strategic planning processes provide the mechanisms to establish an asset management vision and direction. The key question to be addressed is: "What policy and strategic objectives should the asset management strategy advance?"

Asset management is most effective where there is a clear link between the agency's performance objectives and the goals and strategy set for asset management. Establishing an asset management policy and strategy helps to focus management and business processes on the agency's business objectives, which are usually the outcomes of most importance to customers (for example, safety, reliability, and cost effectiveness). This top-down connective thread is a key feature of an asset management system—the clear "line of sight" from organization direction and goals down to individual, day-to-day activities.[5]

[5] PAS55-2: 2008 Asset Management Part 2: Guidelines for the Application of PAS55-1, British Standards Institute, 2008.

Asset management planning is best addressed at the enterprise level as part of the agency's overall business planning. For agencies pursuing strategies to become better asset managers, asset management planning provides the implementation plan to accomplish this. This planning addresses coordination across departments to better work toward common goals. The asset management policy, strategy, and planning processes are discussed in more detail in Section 3.

Lifecycle Management

The lifecycle management of individual assets involves a common set of activities. Managers evaluate the lifecycle cost, condition, and performance of each class of assets—ideally during the design/procurement stage. They link lifecycle management expenditures, such as rehabilitation, preventive maintenance, and unplanned maintenance to asset performance such as mean time between failure and cost. This data-driven practice aims to maximize asset performance, minimize the total cost of ownership, and manage risks. These activities are common to all asset classes but differ in how they are performed, as discussed in the *Asset Management Guide Supplement*.

The common activities include the following:

- **Asset Inventory** – An asset inventory is a register, or repository, of an agency's assets and information about those assets. It is intended to provide accessible, consistent, and comprehensive information about that asset class. It is also intended to provide consistent information across all asset classes to support enterprise-level business processes, including capital programming and operations and maintenance budgeting.
- **Condition Assessment and Performance Monitoring** – Each asset class has different requirements for condition inspection and monitoring that depend on their performance characteristics, the risks, and impacts of failure. Gathering condition and performance data can be costly, so agencies often have strategic approaches to gathering the data that is most cost-effectively acquired and valuable. This information is used to improve reliability through an agency's ability to predict failure and address the root causes and proactively plan for the investments required to maintain good performance on the most critical assets. It also is used to manage risk and determine needs to be addressed in asset management plans.
- **Lifecycle Management Planning** – A lifecycle management plan documents the costs, performance, and risks associated with an asset class throughout its life. This plan can be used to ensure that the performance expectations of the asset are understood and fit within the agency's broader goals and performance objectives, and that all investment decisions are transparent, well-communicated, and support the agency's goals.

The lifecycle management processes are discussed in more detail in Section 3.

Cross-Asset Planning and Management

This guide incorporates asset management into a transit agency's enterprise-level decision-making processes, including capital planning and operations and maintenance budgeting. At the enterprise level, such plans are used to communicate the level of service that can be delivered at different funding levels, and make performance-based decisions in financially constrained capital plans and budgets. In this guide, a distinction is made between decision making across multiple asset classes—often referred to as "cross-asset" resource allocation—and the lifecycle management of particular asset classes. These processes combine asset data gathered and evaluated at the asset-class level for decision making at the enterprise level. For example, lifecycle cost and performance data gathered for railcars can be combined with comparable data for traction power systems to determine how capital and operations and maintenance funding should be programmed most effectively. Similarly, agencies can use asset condition data and other analysis in a predictive model to evaluate future costs and asset performance under different funding and level-of-service scenarios.

The asset management plan addresses cross-asset business processes, including capital planning and programming, operations and maintenance budgeting, and scenario evaluation and management described in more detail in Section 3.

Information Technology Systems

Information technology is a critical asset management enabler. Contemporary best practice—either at the enterprise level or during any aspect of lifecycle management for individual asset classes—is data driven and requires the application of information technologies. As explained in the asset management framework, information systems are foundational to any asset management initiative. Whether an agency is developing its asset inventory or using condition data over time for performance modeling, the asset data needs to be stored, managed, and analyzed in one or more information systems. Information systems can support all of the asset management business processes. Section 4 describes the use of asset management information systems and summarizes the implementation principles associated with these tools.

Maintenance Management and Asset Management

The terms "maintenance management" and "asset management" are frequently used interchangeably in the industry when, in fact, they are separate. While the primary purpose of maintenance management is to manage maintenance activities (which activities are performed on which asset, cost of maintenance), the primary purpose of an asset management system is to provide a whole life view of all assets, to allow monitoring, tracking, and analysis of how funding strategies affect asset condition, and to allow the agency to make policy and strategic decisions regarding funding (cross-asset decision making, investment decisions). Maintenance management is focused more on the short term activities, while asset management is intended as a proactive approach to managing enterprise investments over the longer term. Maintenance management should be envisioned as a subset of asset management. The term "enterprise asset management" refers to asset management conducted at an enterprise level instead of just one section/ department of the agency/enterprise. The maintenance management system, when integrated with business intelligence, condition tracking and forecasting, and other enterprise tools, forms a true enterprise asset management system/tool.

Other Enablers

Enablers are supportive processes and activities that are foundational items for a successful asset management initiative. Displayed as the bottom panel in the asset management framework, enablers ensure that the asset management business processes can be successful. Many of the enablers require dedicated resources (staff and/or funding); however, in many cases, they can be integrated into an agency's existing enabling processes. Enablers include leadership and accountability, training, communications, values and culture, project management, and continuous improvement. Enablers' importance and associated success factors are discussed in more detail in Section 5.

Asset Management and Sustainability

A sustainable institution supports the long-term viability of the community and environment. As such, sustainability represents a key subset of public transit's core mission. For transit agencies, sustainability aims to:

- Reduce resource use, pollution, and waste.
- Improve the efficiency of existing systems and processes.
- Establish transit as a central part of a robust set of sustainability transportation options.
- Support smart growth and livable communities.

These broad objectives represent another set of considerations for the management and operation of transit assets. At each stage in the asset lifecycle, sustainable asset management involves (1) using resources more efficiently to reduce the agency's environmental footprint, (2) managing waste responsibly, (3) building and supporting healthy spaces, and (4) planning for climate change. By focusing on these shared objectives, transit systems can benefit from energy price stability and cost savings, improved employee productivity, reliable service, improved integration of transportation modes, and supportive land use that provides mutual community benefits, aligned through a sustainability framework. The role of sustainability in asset management is discussed in more detail in the *Asset Management Guide Supplement*.

Strengthening Asset Management Practice—Implementation Principles

The fundamental concepts of asset management are straightforward; however, implementing the changes required to establish mature asset management processes can be challenging. Implementation requires managing across functional areas and integrating decision making across the life of often long-lasting assets. Strategies to consider to help meet these challenges are:

- **Understand an agency's asset management drivers** – Agencies undertake asset management for different reasons (response to a mandate, need for improved transparency, and need to improve performance, among others). Agencies should develop an implementation approach that maintains that focus; however, the approach should be flexible enough that it can shift as priorities change.
- **Build upon existing strengths and practices** – Agencies should leverage their departments' existing asset management activities, identifying their best practices and lessons learned with one asset class and applying them to others.
- **Provide value immediately** – Through incremental implementation activities, an agency can achieve results quickly that demonstrate the value of implementing improvements to asset management practice and provide momentum for future activities. A solid foundation can be created while still acknowledging the long-term nature of an asset management initiative.
- **Recognize that asset management is a process** – The guide identifies the core processes, which provide a starting point, but agencies should recognize the importance of continually improving processes and organizational learning.
- **Prioritize people, tools, and information** – Asset management, at its core, is about data-driven management, so managers should identify the people who can understand and lead this change initiative and the data and tools that best support the agency's decision-making processes.

- **Invest smartly** – Identify the investments that will provide the best "bang for the buck" and only if these investments support the agency's strategy.
- **Focus on human resources** – Identify the appropriate skillsets needed to implement the asset management strategy and invest in those people–with recognition, incentives, and training.
- **Assign clear ownership of asset management activities** – Agency leadership should provide top-down support to establish an asset management culture and mandate for managers, while asset owners should "own" and drive implementation by developing and implementing lifecycle management plans.

Section 5 provides guidance on implementation and resources, including an agency self-assessment from which to review "asset management maturity" and guidance for how to get started.

Vision of a High-Functioning Transit Agency

Improving asset management practices may seem too "long term" to be a priority, given the pressing, day-to-day operational realities and policy concerns; however, there are defined components with measurable outcomes that can put agencies on the path to a more business-like practice. This guide details these components and explains how an agency can implement them. This section describes the vision of a hypothetical agency after having successfully implemented asset management strategies. The following describes an agency—both before and after implementing the asset management strategy—from the perspective of many of the influenced stakeholders.

General Manager

"As the General Manager, I have noticed a transformation in the culture of this agency. Inter-departmental meetings occur on a regular basis, staff members seem more invested in their jobs, and everything we do seems to have a basis in numbers—numbers that we actually trust! I can see that the employees understand how their job relates to our agency's strategic objectives (better reliability, safety, and customer service). We better understand and are able to manage risk in each of these areas. My relationship with the board and other stakeholders seems to be improving every day, and our riders, generally, seem to be more satisfied.

This was an executive team initiative driven by our financial challenges and our desire to apply more business-like practices to improve performance. Together, we created a vision for how to change the agency so that our existing assets could be managed more effectively. We understood that it would require involvement and buy-in from staff in all departments and at all levels of the organization. It would also require some serious discussions with the Union, so we started the whole process by leading small workshops to get input from all of these people. Based on the discussions at these workshops, I created an asset management leadership team composed of staff from various departments that, from my point of view, seemed to "get" our vision. As a group, we evaluated our agency's strengths, weaknesses, opportunities, and threats with regards to asset management. and in that regard, we developed goals that target safety, reliability, on-time performance, and cost effectiveness. We talked about what kinds of performance measures would help us to see how we were doing in reaching our goals, and we developed a plan that outlined how to make it all happen.

Two years later, our agency is still working towards that vision, but we've come a long way. We take an entirely different approach to decision making. Now, we can pretty accurately predict all of our assets' lifecycle costs because we involve engineering, operations, and maintenance people in developing asset-specific lifecycle plans for every asset class. We can show how an asset will underperform without appropriate capital and maintenance investments. We also can show how this will impact our over-arching asset management goals. As time has gone by, all of our cost and performance data has gotten better and better. We understand our costs much better and have visibility to our future capital and operating expenditure needs.

All of this data has been put to good use. We manage based on what "we know" not "what we think we know." Our operations and maintenance budget is built from the bottom-up based on real cost data that we trust, and our capital program is prioritized based on the needs that best serve the goals we established. Our staff members know and understand how their jobs relate to our overall goals, and they've got goals and performance evaluations that are supportive of these goals. Our Information Technology (IT) group has been a great partner in our recent successes. After mapping all of the systems and data that we were storing and maintaining in multiple locations, our IT group developed a strategy for integrating our asset inventory data and linking it to any tools that supported the analytics behind our asset management goals. Everything we did supported our goals in some way! Quantitative data (including both costs and performance data) are constantly being evaluated and updated in our asset management system. We know our predictive data will never be perfect, but operations, maintenance, and engineering staff are constantly looking for ways to improve it. Now, I can access high-level summary reports from our systems, and the maintenance group can download asset-specific maintenance and performance reports.

The asset management team continues to re-evaluate our strategy, monitor our performance measures, offer training, and communicate with all of our departments. They know as well as I do that we can always do better, but we also know how far we've come!"

Maintenance

"As the Chief Maintenance Officer, I was initially a bit skeptical about the asset management effort. We had pretty good, data-driven processes happening within our group before the asset management improvement effort was started. All of our maintenance jobs were tracked within a system, so we could tell you about every maintenance activity that occurred on all of the assets. Our maintenance managers usually noticed when we were fixing the same asset over and over, so we would request a replacement or a new manufacturer. We didn't really track the parts and supplies, but we have some very experienced mechanics who 'just knew' when we needed to order supplies. I could always use more funding, but the finance group generally gave us the same amount each year. Also, I have a good relationship with the engineering and operations folks, so we would coordinate when we needed to.

Now that we've undergone all of this change, I can see why the asset management effort was important. Our group was keeping track of only the assets' maintenance costs. We never thought about it in terms of the overall cost and performance of the asset. Now, we have a 'spot at the table' when our agency is introducing a new asset class or procuring something from a new manufacturer. We discuss the maintenance requirements of those assets and how capital investments throughout the assets' life can minimize the maintenance costs. We look at those kinds of decisions before we even procure the asset so that our finance people can make informed decisions later on. We are now exploring how to apply reliability-centered maintenance methods.

Also, our maintenance staff understands the importance of logging their activities, time spent, and the assets' condition as they complete their assignments. We share the performance reports with them, and they understand how their job contributes towards the assets' condition, which contributes to the assets' performance, which contributes towards the agency's goals. We celebrate whenever we make big improvements or hit a target!

In addition, we are likely to realize savings as our spare ratio requirements are falling, and we are talking about how we've been able to realize millions of dollars in savings by taking advantage of our warrantees. The transparency of our activities has given our group more credibility, so maintenance activities are now receiving a larger portion of the available funding."

Engineering

"As the Chief of Engineering, I used to spend most of my days 'fighting fires' and making sure that broken equipment was getting fixed as quickly as possible to minimize service disruptions. I used to get asked pretty regularly what my highest priority projects were because it was time for our annual capital planning process or because a grant became available. Thankfully, I have worked here long enough to know our highest priority needs, but I used to worry about what would happen when I and others retire in the next few years.

Since our asset management effort began, I've noticed that my job has changed significantly. We now have lifecycle management plans for all of our major asset classes, so I'm able to review all of the needs across the system and prioritize them with a clear rationale. I used to do this in my head before, which worked relatively well, but it wasn't very transparent. We now have a capital plan that clearly identifies where our priorities are in the short and long term. All of this information has actually helped to improve our procurement process as well. We're able to put much better definition around the scope of our needs (including asset condition and performance requirements), so contractors are able to provide us with better contract bids and design submittals.

Now that the board and others understand all of our project needs, we're actually getting more funding than before, so we have been able to address our backlog and proactively rehabilitate our assets based on their priority in the system. Our department still "fights fires," but we're doing that a lot less than before. I now feel like I could retire and a lot of my knowledge of the system is being preserved through updated asset management processes and tools.

Operations

"As the Chief of Operations, I wasn't sure how our group would be involved in the asset management strategy. I met with the Chief Maintenance Officer and Chief Engineer whenever we had consistent breakdowns or malfunctions. There's a constant struggle over whether to spend capital money to replace an asset or spend operations and maintenance funds to maintain it.

Now, these decisions seem to be made entirely differently. Everyone, including the finance department, bases their decisions on performance. This means that, as an agency, we are looking very closely at whether we are meeting our pull-out schedule, how often there are failures or safety incidents, and what our customers are saying at public meetings and at our call-in center. We are quickly evaluating the source of our issues and measuring what the most cost-effective strategies are for improving our performance. I now have regularly-scheduled meetings with our maintenance and engineering folks, and these cross-departmental meetings are happening at the lower levels as well. Our operators are much happier and our on-time performance has improved significantly."

Capital Programming

"As the manager of Capital Programming, I am thrilled with the total transformation of our capital program prioritization process. For years, we have been trying to have a transparent, data-driven process for prioritizing the state-of-good-repair needs (our expansion needs are generally funded and prioritized separately). On an annual basis, our group would send out forms to each of the department heads so that they could list out all of their capital needs. We had significant issues trying to separate the highest need projects from the 'wish list' projects, and we often had to trust what one or two managers told us. We also didn't believe the cost estimates that were provided, since the majority of the projects ended up costing us a lot more than what we had budgeted. The worst part was that we would go through a tremendous effort to prioritize the needs as best as possible, and then our executive team would approve different projects!

Now the process is much more data-driven and transparent. We have outlined a clear process for identifying capital needs, getting input from all departments, prioritizing them based on our agency's goals, and then letting the executive team make the final decision. The prioritization criteria are based on cost and performance data that are consistently compiled for all of the assets, so we're able to compare assets throughout the organization. Also, our executive team understands the prioritization process and they trust the underlying data, so they generally support the recommended program that we develop. My team feels more connection to the agency, its goals, and the service we're providing because we're working so much better with the other departments and seeing our connection to the larger picture."

Long-Range Planning

"As the head of our long-range planning group, I was thrilled to be included in the asset management strategy. Our group regularly assesses the capacity requirements of our region—both in the short and long term—so it's been helpful to participate in the asset lifecycle discussions. Most recently, the engineering group did not realize how our customer demand has been shifting and how that could influence the vehicle procurement. This led to a complete change in the size and type of vehicles being procured. I have also found that our group now incorporates much better asset lifecycle data into our expansion plans, which seems to have made them much more accurate than before. I can actually see how these cross-departmental discussions and data sharing are directly improving service to our customers."

Finance

"As the Chief Financial Officer, I am excited by how the asset management strategy has transformed the way we handle all of our financial activities. Generally, the department heads used to come to us when they had financial needs and we went to them when we needed information to support our budgeting processes. Now, our financial activities are much more closely tied to their processes, and we all understand how our decisions impact the agency's goals. The operations and maintenance budget is based on engineering and maintenance cost forecasts developed through the asset lifecycle management process. Our accounting system now receives information from the centralized asset inventory, so the accounting staff no longer needs to chase down paper records or asset managers to address accounting requirements. The biggest difference is that staffs understand how we're making financial decisions, so we're all functioning like a team."

Board Member

"As a board member, I have been very impressed by the improved transparency and communications. We expect the agency to apply best practices, learn from other industries, and improve performance. I understand the importance of asset management in accomplishing this. At our board meetings, the General Manager has been sharing performance reports that include explanations and mitigation strategies for all performance measures that are below our agency targets. We are seeing general improvements in all of our goals, and we understand the importance of additional funding in continuing this trend. This additional information has forced us to shift our focus from expansion to our existing assets."

Customers

"As a regular rider, I have noticed significant changes in the transit system. The buses seem to be a lot more reliable; they show up when I expect them to, and they seem to be a lot cleaner than they were before. I feel more comfortable relying on the transit system to get me to where I'm going when I need to get there."

SECTION

3

This section describes each business process in the transit asset management framework introduced in Section 2. For each business process, this section describes what best practice looks like, key implementation activities and challenges, and peer examples.

Asset Management Framework Business Processes

The transit asset management framework has three categories of business processes (see Figure 3-1):

1. **Asset Management Vision and Direction** – These are agency-wide processes that establish the organization-wide asset management policy and strategy and drive resource allocation.
2. **Lifecycle Management** – These are the processes involved in the lifecycle management of individual asset classes. These include managing the data (inventory), monitoring the assets' condition and performance, and developing lifecycle management plans.
3. **Cross-Asset Planning and Management** – These are agency-wide processes that consider information from all asset classes to support the capital programming and operations and maintenance budgeting process.

Each of these categories of business processes are described in more detail in this section.[5]

[5] "Information Technology Systems" are discussed in Section 4 and "Enablers" are discussed in Section 5.

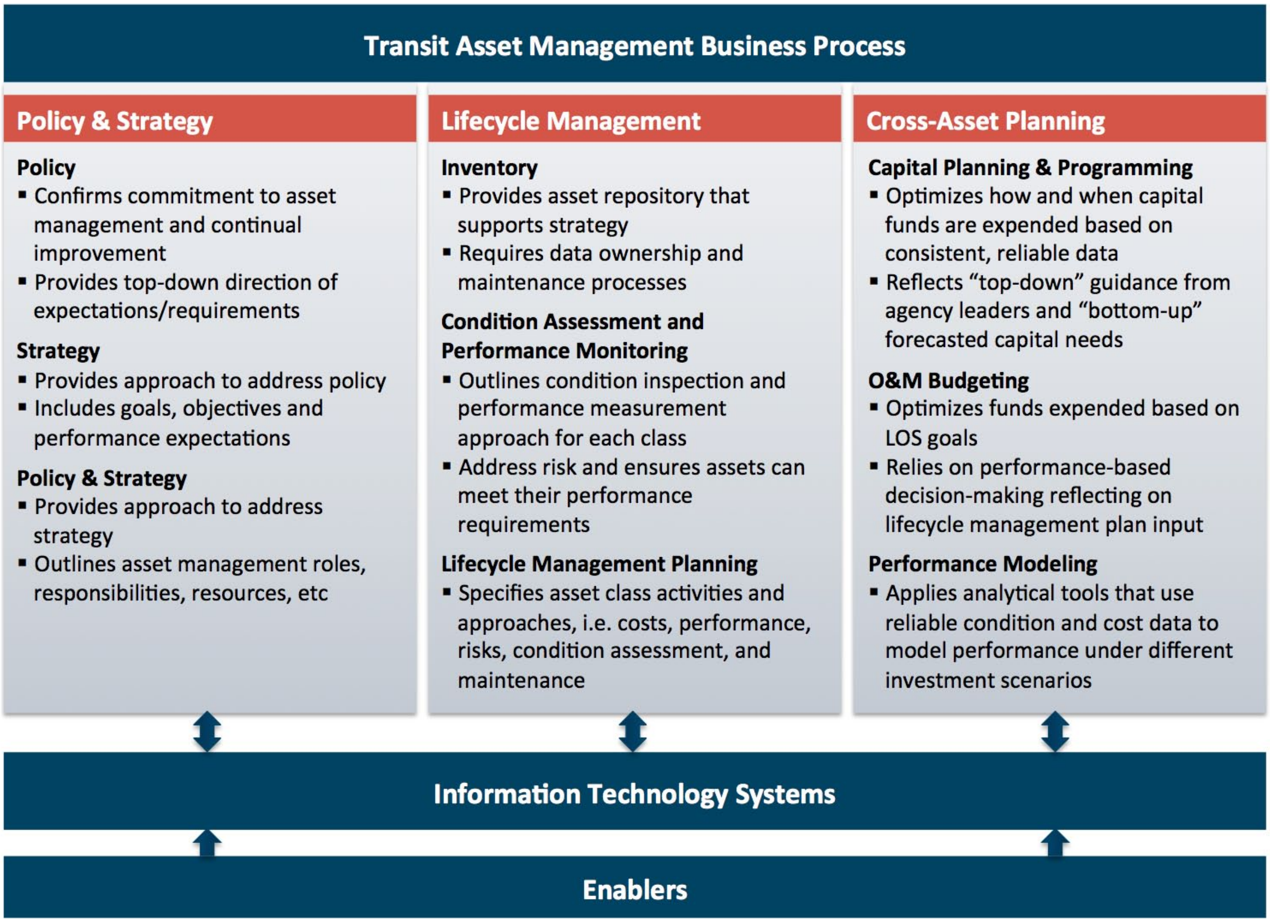


Figure 3-1 *Transit Asset Management Framework Business Processes*

Asset Management Vision and Direction

When effectively integrated into an agency's business practices, transit asset management crosses functional boundaries, such as operations, engineering, planning, and finance. It requires managing across classes of assets (including buses, rail maintenance facilities, and bridges) and looking beyond the current budget cycle.

Institutionalizing asset management and establishing an asset management culture through a clear, consistent policy and strategy is a critical component of the successful leadership and management of a transit agency. This is best accomplished when an agency's existing policy and strategic planning processes provide the mechanisms to establish an agency-wide asset management policy, strategy, and plan that address implementation responsibilities and accountability.

Asset management policy and strategy are typically set by executive management and adopted by the agency's governing body. These may be incorporated into an agency's existing policies and strategies or developed independently. The asset management plan can then be developed to include implementing actions that address the asset management policy and strategy.

Transit agencies' management processes have traditionally been siloed into functional areas and technical disciplines. For example, design decisions do not always address input from the operations department regarding actual operating costs. Similarly, capital investment decisions are sometimes made without consideration of the maintenance implications. Policy and strategy are important in setting expectations for managing across silos and set the tone from which to establish a strong asset management culture. They provide a link to planning, budgets, and day-to-day work performed across all departments. The roles of asset management policy, strategy, and planning are shown in Table 3-1 and discussed in the following sections.

Figure 3-2

Asset Management Vision and Direction Business Processes

Policy & Strategy

Policy
- Confirms commitment to asset management and continual improvement
- Provides top-down direction of expectations/requirements

Strategy
- Provides approach to address policy
- Includes goals, objectives and performance expectations

Policy & Strategy
- Provides approach to address strategy
- Outlines asset management roles, responsibilities, resources, etc

Table 3-1 *Asset Management Policy, Strategy, and Plan – Definitions and Contents*

	Policy	Strategy	Plan
What is it?	• Confirms agency's commitment to asset management and continual improvement. • Provides top-down direction regarding expectations and mandatory requirements. • Broadly outlines the scope of asset management through enterprise-level asset management direction. • Links asset management to agency vision, mission, and goals. • Specifies expectations for the role, focus, and level of asset management practice. • May establish broad agency policy statements for asset management, such as: - Optimizing the use of funds across an asset's lifecycle - Improving agency-wide reliability - Incorporating environmental sustainability goals into asset decision making.	• Outlines the agency approach for accomplishing the asset management policy. • Addresses organization, business processes, and tools. • Includes specific, measurable business objectives (for example, reliability, cost of service, such as *Increase the percentage of agency assets with a condition rating over 2.5 (out of 5) to 80% of all assets by the end of 2015*. • Provides high-level direction and expectation for asset management by asset class and functional managers. • Provides clear direction for prioritization process.	• Specifies the activities to be pursued to address policy and strategy. • Sets performance management expectations for the various business areas in terms of preparing and implementing lifecycle management plans and delivering asset performance. • Specifies implementing actions for improving asset management practice and increasing asset management maturity.
Typical Contents?	• Organizational context (overall vision, mission, and strategic goals) and goals and roles for asset management • Consideration of any mandatory asset management requirements (those things an agency establishes by policy as mandatory)	• Asset management objectives and expected outcomes • High-level description of asset management activities (people, information systems, processes, etc.), timelines, and responsibilities • Asset management relationship to delivery of service and other business processes • Asset management approach to stakeholder consultation	• Detailed asset management activities, roles, and responsibilities, resources, and timelines • Requirements and plan for developing asset-specific lifecycle management plans • Process and tools required to manage and store asset data • Asset management continuous improvement strategy activities, including resources and timelines. This includes enterprise-wide and asset-class specific improvement projects

Role of Asset Management Policy

An asset management policy provides top-down direction for the entire agency. This direction can be vital for an asset management initiative because, depending on the selected implementation path, it can require organization-wide change. To be most effective, asset management policy provides specific, mandatory direction and guidance to be addressed in transit agency strategic planning, business plans, and day-to-day decision making.

An asset management policy is highly visible, frequently referenced, and used by leadership to communicate the direction and expectations for an organization; it is established alongside and with the same level of specificity as other agency policies. The policy addresses the role of asset management in gauging agency performance and meeting level-of-service objectives, and it broadly outlines the scope of asset management by providing the appropriate focus and expected level of asset management practice. In an agency with many different asset classes, policies provide expectations for consistent management practice across asset classes.

Asset management policy success factors:

- Highly visible and used by leadership to provide direction and guidance for all asset management strategy and activities
- Addressed in agency's policy and goal setting processes
- Adopted and integrated into agency's Strategic Plan
- Adopted and integrated into capital, operations and maintenance standard operating procedures
- Integrated into agency talent management and training efforts

The benefits associated with having an asset management policy include the following:

- Communicates agency's commitment to asset management
- Facilitates establishment of a culture that values asset management and makes it a priority
- Embeds asset management responsibilities and accountabilities into strategic planning activities
- Provides leadership and direction and builds a culture favorable to embedding asset management into ongoing capital, operations, and maintenance activities

Key implementation principles associated with the establishment of an asset management policy include the following:

- Policies are not just words—they communicate leadership directions, expectations, and agency requirements for success.
- Policies not only support an agency's goals, but also address the role of asset management in meeting the agency's objectives.
- Policies consider regulations and other business requirements established by outside entities (for example, the federal government, state government, city agencies, and lending institutions among others) that may or may not support the asset management goals.
- For each asset management policy, the agency understands its purpose and impact on goals, and how to ensure that it is followed.
- Agency management, staff, and the board have the opportunity to provide input and understand implications of the asset management policy.
- Broad participation and input to asset management policy is sought from management, staff, risk managers and other stakeholders, and the board. These parties are then engaged in the process, have a thorough understanding of the agency's processes, and are supportive of potential funding requests that may result.

Role of Asset Management Strategy

The asset management strategy addresses how the policy will be implemented. This guide considers establishing an asset management strategy to be an important driver of change that sets direction. Strategy is implemented through annual business planning and performance management practices. Specifying measurable objectives that are to be accomplished through the strategy provides accountability and focus for business planning and agency management. The strategy needs to be communicated clearly, and the relationship to other enterprise-level management processes, such as performance management, needs to be understood within the agency.

The asset management strategy includes high-level descriptions of the asset management activities necessary to address the asset management policies. The description of these activities includes an overview of the agency's staff, information systems, and business processes. While the plan addresses the day-to-day responsibilities and requirements, the asset management strategy highlights the overall timelines and milestones to be achieved, the relationships between various business processes, and the inputs and priorities for the budgeting process.

Examples of asset management policies are outlined below:

"Develop a comprehensive program that emphasizes cost effectively extending the useful life of equipment, fleet, and facilities, and making capital replacement expenditures only when cost of maintenance warrants the expenditure." *– U.S. Transit Agency (Source: 2011 Parsons Brinckerhoff Survey)*

"Our assets are managed strategically by utilizing integrated and systematic data collection, storage, analysis and reporting standards on a broad range of transportation system assets, optimizing funding and lifecycle decisions for operations, maintenance and construction business functions." *U.S. State Department of Transportation (Source: AASHTO Asset Management Guide)*

"With a tag line of 'fix it first,' [the Agency] will prioritize maintenance and capital reinvestment of its current system over major system expansion." *– U.S. Transit Agency (Source: 2011 Parsons Brinckerhoff Survey)*

The strategy includes realistic, achievable asset management objectives with the following attributes:

- **Specific** – Objectives are clearly described with details regarding what is to be accomplished, for what purpose, during what time period, and within what boundaries. (*What do I want to accomplish? Why do I want to accomplish it? Who is involved? How will it get done and when?*)
- **Measurable** – Objectives are able to be evaluated according to whether they have been achieved. (*How will I know I've accomplished my objectives?*)
- **Attainable** – Objectives are realistic and attainable under "normal" circumstances (including existing resources). (*How can these objectives be accomplished?*)
- **Relevant** – Objectives are supported, believed, and add value for the appropriate stakeholders. (*Are the participants willing and able to support these objectives?*)
- **Time-Constrained** – Objectives have a targeted completion date for the purpose of establishing urgency. (*When should these objectives be completed?*)

Rolling out an asset management strategy requires agency-wide change, which relies on leadership that can manage across traditionally siloed business processes.

The benefits associated with having an asset management strategy include the following:

- Sets agency-wide vision and direction that enables management across functions and different services
- Provides guidance and justification for investment decisions
- Establishes accountability and performance management expectations

"Implementing an asset management strategy at our agency is a goal that has been formally adopted by the Board of Directors. Having this direction coming from the Board conveys its importance."

– U.S. Transit Agency Manager
Source: 2011 Parsons Brinckerhoff Survey

Key implementation principles associated with the establishment of an asset management strategy include the following:

- The asset management strategy is communicated clearly and articulated by leadership so that management, supervisors, and employees at all levels are able to understand and relate their responsibilities to strategy.
- The asset management strategy is developed in the context of performance and risk management, and by setting the level and quality of service objectives.
- The asset management strategy reflects input from relevant internal and external stakeholders to ensure that the strategy is clear, attainable, and most importantly, that these stakeholders feel buy-in towards achieving the strategy.

Examples of asset management objectives include the following:

- Increase on time performance (defined as number of vehicles that pull out of maintenance facility within 2 minutes of scheduled departure time) to 90 percent for all modes by June 2014.
- Maintain customer service with elevator and escalator uptime at 99 percent throughout fiscal year 2014.
- Increase our customer satisfaction score by 20 percent in fiscal year 2013.
- Decrease number of safety incidents (measured per 1,000 vehicle miles traveled) by 5 percent in fiscal year 2013.
- Decrease system maintenance time to 10 minutes or less on all lines in fiscal year 2013 (measured based on travel time impacts of slowdowns caused by track condition).
- Increase the percentage of agency assets in a "state of good repair" (that is condition rating over 2.5) to 80 percent of all assets by the end of 2015.

Case Study

London Underground: Strategy

Relevance of Case Study

This case study demonstrates how a highly mature asset management transit agency revolves all asset management activities and decision making around a clear, communicated strategy with associated measures.

Agency Overview

London Underground (LU) operates "the Underground" or "the Tube," providing metropolitan rail service for approximately 1.01 billion passengers per year. It is a subsidiary of Transport for London (TfL), which is responsible for London-area transportation services (urban and suburban). According to the FTA's review of transit asset management practices, the LU has the following assets:

- 11 tube lines
- 243 miles of track
- 276 stations
- 4,070 rail cars

In 2003, elements of the LU operation were effectively privatized and divided into three private-sector infrastructure companies (InfraCos) that were managed by two providers: Tube Lines and Metronet. The InfraCos signed contracts for the maintenance, renewal, and upgrades of the rolling stock and infrastructure, including trains, tracks, tunnels, signals, and stations for a 30-year period. In 2006, Metronet went bankrupt, prompting the LU to take over management of two of the three InfraCos; in 2010, Tube Lines withdrew from the contract, selling its interests to TfL.

Asset Management Approach

London Underground strives to uphold the asset management objectives of TfL, which include "ensuring current service levels are supported" and "achieving a state of good repair, addressing a backlog of maintenance or asset replacement." LU established asset management measures in the following areas:

- Ambience (comfort/amenities) of trains and stations
- Availability of the infrastructure, with loss of availability measured by lost customer hours
- Capability of the infrastructure to provide service, measured by passenger journey time

- Fault rectification (resolution), measured by response time established by type of defect

London Underground's business strategy optimizes maintenance and asset replacement by maintaining and replacing assets based on the practice of "best whole-life asset management." Using the "best whole-life" management concept allows the LU to purchase and maintain its assets based on an understanding of the cost of ownership across the entire lifecycle of each asset.

London Underground has developed a system for measuring asset performance that helps to prioritize investments and streamline maintenance across the agency. Asset performance is reviewed every four weeks at an Asset Performance Review Maintenance meeting. Key measures include mean time and mean distance between in-service failures, as well as lost customer hours. Asset condition is summarized by the percentage of assets in each of four different residual life categories:

- Category A assets are estimated to have at least 10 years of residual life.
- Category B assets are estimated to have 6 to 10 years of residual life.
- Category C assets are estimated to have 1 to 5 years of residual life.
- Category D assets are estimated to require overhaul or replacement in less than 1 year or are time expired.

Any concerns (risks) relating to the condition of the assets are quantified financially and categorized between 1 and 4 relating to statutory non-compliance, safety, requiring extraordinary maintenance, or having a performance impact, respectively.

It is up to managers to understand the strategies for the assets that they are responsible for and communicate with their direct reports accordingly. Employees have access to business scorecards that have a series of measures, which, if delivered, will result in the successful delivery of the asset management plan. These are reviewed with employees on a daily, weekly, and monthly basis.

Benefits/Outcomes

- Capital and operating funding is directed at the assets and associated projects that have the greatest impact on our strategic objectives (e.g., customer service).
- London Underground takes performance and safety risks into account, which creates a focus on future performance that allows asset managers to optimize expenditures between different asset groups.
- Improved asset management processes have ensured a clear line between the agency's overall strategy, the asset management plan, and front line delivery.

Source

Information provided by a senior contact at the TfL.

Role of Asset Management Planning

Asset management planning is a process that establishes the activities necessary to address policy and strategy at the enterprise level and asset class level. At the enterprise level, the plan provides direction for cross-asset business processes. At the asset class level, the plan provides direction to line managers regarding oversight and accountabilities associated with their respective asset classes. An asset management plan is incorporated into the agency's annual planning and budgeting.

In this guide, the asset management plan addresses asset management processes, activities, tools, and annual asset management work planning and budgeting. The guide includes implementation plans for change initiatives that will improve asset management practice and maturity. This is distinct from the lifecycle management plan, which is the plan for the lifecycle management of asset classes and their integrated management (see the *Asset Management Guide Supplement*).

An asset management plan outlines the activities that will be implemented and resources applied to address the asset management policy and strategy. For transit agencies using this guide, the plan will address the activities and changes to be implemented to increase the maturity of asset management practice.

Asset management plans have two major components:

- Enterprise-wide implementation actions that provide enabling support and direction for asset management across all asset classes and services.
- Direction and expectations for asset class owners and department managers regarding lifecycle management planning and processes—with a focus on the lifecycle management plans (see later in this section).

The plan outlines how people, processes, and tools come together to address the asset management policy and goals. The plan provides accountability and visibility for increasing the maturity of asset management practices, and can be used to support planning and budgeting activities, communicating to internal and external stakeholders, and as an accountability mechanism. Table 3-2 provides the recommended contents of an asset management plan.

"An asset management plan, even when complete, needs to be dynamic because the agency will evolve over time."

– U.S. Transit Agency Manager
(Source: 2011 Parsons Brinckerhoff Survey)

Benefits of having an asset management plan include the following:

- Increases the maturity of asset management practice, which can improve the agency's performance
- Improves stakeholder relations and accountability
- Establishes accountability for implementation

Table 3-2

Asset Management Plan Contents

Section Name	Contents Description
Asset Management Policy and Strategy (What are the asset management goals?)	States asset management policy and strategy and describes process for developing these. It also explains the relationship to agency-wide policies and strategies. This section explains the past year's accomplishments and planned progress toward goals and objectives.
Implementation Strategy (What needs to happen to implement asset management strategy?)	Outlines a plan showing the activities necessary to achieve the asset management goals (including all aspects of change management). This plan outlines a schedule with roles, responsibilities, accountabilities, tasks, and dependencies.
Key Asset Management Activities (What will be accomplished in the next year?)	Lists the key asset management activities that are planned to be accomplished in the upcoming year. If appropriate, this can be where the selected implementation path (see Section 5) is described. *Examples of activities include combine three departments' asset inventories, develop a lifecycle management template and populate it with information from three most-critical asset classes, or hire asset management program manager.*
Financial Requirements (What are the estimated capital and operations and maintenance costs?)	Specifies the resources (including internal staff time, consultant time, technology requirements, and materials) needed to develop and implement this plan. This information should be easily transferred to the agency's capital program or operations and maintenance budget, as required.
Continuous Improvement (How can we ensure we continue to get better at asset management?)	Outlines how this plan and all related business processes will be revisited and updated, as needed, to ensure that the organization is embracing continuous improvement of the asset management initiative.

Key implementation principles associated with the establishment of an asset management plan include the following:

- The plan is part of the agency's business planning processes (such as strategic planning or capital planning) and provides the process through which implementation budgets and accountabilities are established. This process addresses dependencies, including reliance on the hiring of new staff, funding availability, or software development. It also reconciles asset management priorities against other agency initiatives.
- Implementing activities are based on an assessment of how well they accomplish the business objectives. To the extent possible, the activities address specific problems or deficiencies that improve performance.
- The plan is established by a cross-functional team of managers (see Section 5) and is updated annually (or more frequently if it is newly developed or if

there are significant asset management activities occurring in a shorter time period). The plan includes input from leaders from all affected departments and is approved based on the established accountability structures.

Asset management plan success factors:

- Commits the resources for asset management activities needed to address policy and strategy at the enterprise and asset class levels
- Links the organization's main business processes, including the performance management, risk management, and budget processes
- Provides specific accountabilities regarding scope and timing for implementation activities

Case Study

King County Metro Transit: Asset Management Planning

Relevance of Case Study

This case study demonstrates how a transit agency uses an asset management plan to plan and communicate the agency's asset management goals, how they are' measured, and how asset data feeds into the capital program.

Agency Overview

King County Metro Transit (Metro) provides bus service to all of King County, including the city of Seattle, and operates the Downtown Seattle Transit Tunnel, which is used by Metro and Sound Transit buses and Sound Transit light rail vehicles on the Central Link transit line. Metro acts as the operator of the Central Link line for Sound Transit. Metro's average daily ridership is more than 400,000 passengers and its assets include the following:

- More than 1,300 vehicles
- 130 park & ride lots
- 13 transit centers
- 7 operations and maintenance bases
- 6 support facilities
- 71 miles of trolley overhead wire
- 1 transit tunnel with 5 stations

Asset Management Experience

In Washington State, as a condition of receiving state funds, publicly owned transit systems are required to submit a transit asset management plan (TAMP) to the Washington State Transportation Commission for certification. The plan must inventory all transportation system fixed assets and provide a preservation plan based on lowest lifecycle cost methodologies. The TAMP specifies actions necessary within a six-year window to maintain a state of good repair for Metro's fixed assets and includes the following:

- Mission statement
- Inventory of assets and definition of "state of good repair"
- Roles and responsibilities
- Related business processes, including condition reporting and capital program prioritization
- Asset management work plan, including budget and timeline

Within the current capital improvement period (2012–2017), TAMP expenditures will exceed $10 million per year. The TAMP currently does not fully incorporate all asset information about the Downtown Seattle Transit Tunnel or the newly built structured parking garages. The TAMP also does not include the following asset categories: IT systems (hardware and software), revenue vehicles, and non-revenue vehicles.

The goals of Metro's asset management program are to "preserve existing King County Transit infrastructure and equipment to accomplish the purpose(s) for which they were constructed or purchased," and to "replace equipment and/or infrastructure as indicated by the facilities and equipment assessment, life cycle projections, condition inspections and maintenance reporting."

Metro defines a state of good repair as follows: "An asset is determined to be in a state of good repair when the evaluated asset (system, equipment, or component) is in a condition where/when it can continue to meet and perform adequately for the purpose to which it was acquired and be safely operated and maintained within the parameters set forth by the manufacturer." Assets included in the six-year window are inspected annually at a component and subcomponent level. Clear policies are in place for inspection, maintenance, and rehabilitation practices.

Metro produces an annual Facilities Condition Report (FCR). The FCR documents inspection results and project recommendations for replacement or refurbishment of fixed assets. The FCR is used in conjunction with maintenance records and information on asset lifecycles to determine the optimum timing for assets replacement. Metro annually selects projects from the FCR to include in its capital plan. A team approach is used to develop the FCR and prioritize project implementation. Team members are included from facilities management (the team lead), engineering, design, construction, project management, and budgeting. Also, the team solicits input from stakeholders, including operations and maintenance, long-term planning, and service planning.

Benefits/Outcomes

The TAMP has provided Metro with the following:

- Better understanding of assets' conditions
- Better-identified capital needs
- Better-informed investments (rational decision making and the best use of available funds and personnel)
- Increased staff understanding of the investments required to achieve a state of good repair
- Cost-effective management of assets (according to Metro's current knowledge)

Sources and Other Resources

Information provided by a senior contact at King County.

Lifecycle Management

This section describes a common set of processes that support lifecycle management for each class of transit assets. Lifecycle management is foundational for asset management; it involves inventorying, condition assessment and performance monitoring, and establishing lifecycle management plans for each set of assets (see Figure 3-3). These processes provide the building blocks for a data-driven approach to asset management by providing information on the relationships between work performed and expenditures on assets over their lifecycle and service outcomes.

The activities undertaken to implement these processes will differ between asset classes and agencies. The *Asset Management Guide Supplement* (see Appendix A) provides guidance, standards of practice, and best-practice examples on each of the lifecycle management processes for each major asset class, including, for example, rail vehicles, maintenance facilities, and security systems.

Figure 3-3

Lifecycle Management Business Processes

Lifecycle Management

Inventory
- Provides asset repository that supports strategy
- Requires data ownership and maintenance processes

Condition Assessment and Performance Monitoring
- Outlines condition inspection and performance measurement approach for each class
- Address risk and ensures assets can meet their performance requirements

Lifecycle Management Planning
- Specifies asset class activities and approaches, i.e. costs, performance, risks, condition assessment, and maintenance

Role of Asset Inventorying

The asset inventory process is the approach a transit agency takes in maintaining a register of the assets it owns or is responsible for maintaining. An asset inventory is the first step in organizing and managing asset information. This guide emphasizes the importance of having a process to determine what should constitute the asset inventory, how the inventory should be organized, and the critical information that is needed to manage the items in the asset inventory over their lifecycle.

Regardless of an agency's asset management maturity, the inventory process is foundational. Asset management uses data from the inventory, including descriptive characteristics (such as estimated useful life, estimated remaining useful life, location, year of purchase, cost, quantity, condition, and maintenance history) to support decision making. The asset inventory process provides data that can be used to support asset class–specific business processes (for example, comparing effectiveness of various maintenance practices on one asset class) and enterprise-level business processes (for example, capital programming and operations and maintenance budgeting). These processes require the integration and use of data from multiple sources.

The asset inventory is structured to include a hierarchy of assets that comprise a specific asset class. The asset inventory and the associated asset hierarchy can provide the common basis for integrating this information and using it for multiple purposes across the agency.

A mature asset management agency will have a managed process for inventory, condition assessment and performance analysis, and asset management plans in place for each asset class.

Each of the asset management processes specified in this guide is data-driven and will create requirements for asset information needed in the inventory. These requirements will identify which assets to include, how they should be organized in an asset hierarchy, and what information is needed about the assets (for example, asset attributes).

To develop a robust, data-driven approach to asset management, it is important for agencies to identify their data requirements and, once developed, maintain the data. Figure 3-4 illustrates the activities associated with identifying, organizing, and improving upon asset information. Each of the following sections provides more details associated with these activities.

"An asset breakdown structure [asset hierarchy] is critical as all data flowing from the software system will be based off of that. Take the time to develop an asset hierarchy that works for all business units as much as is practical."

– U.S. Transit Agency Manager
(Source: 2011 Parsons Brinckerhoff Survey)

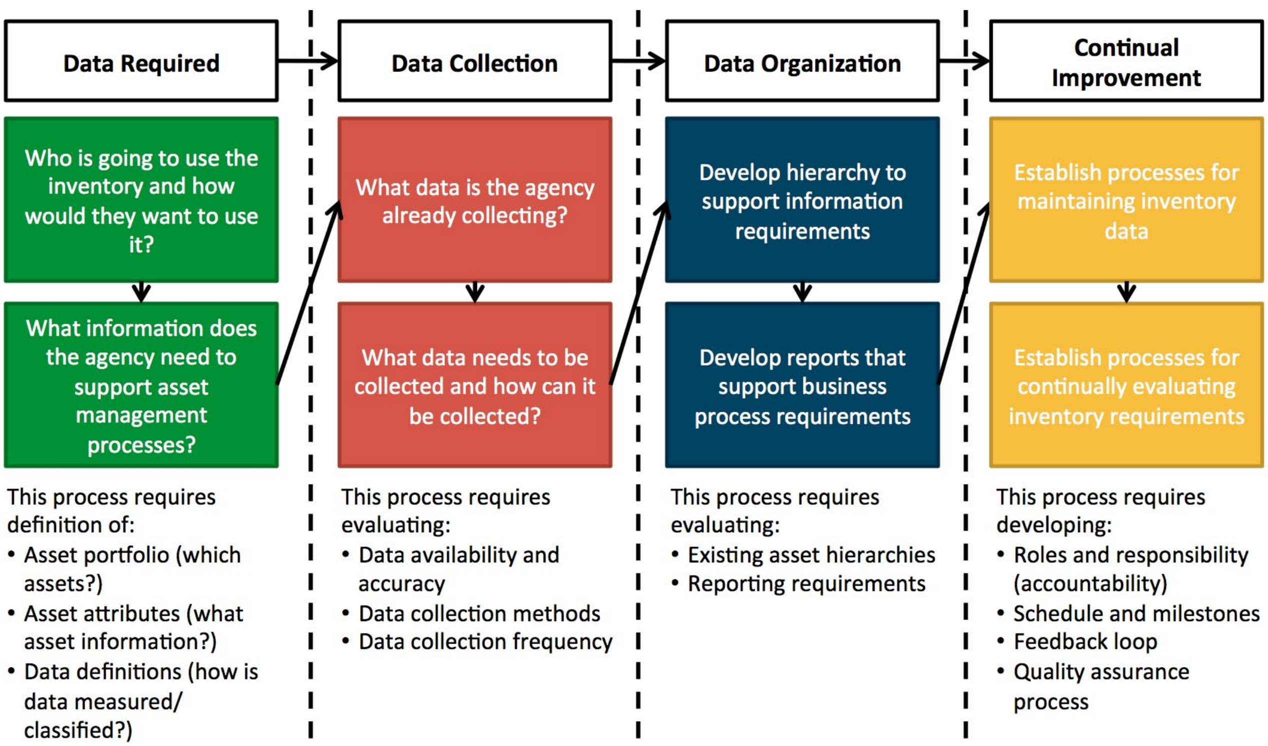


Figure 3-4 *Asset Inventory Information**

* This section focuses on the inventory data and how it is organized, updated, and used. The one or more tools used to manage the inventory are integral in the requirements gathering discussion; however, it is discussed in more detail in Section 4.

The following terminology used in this section is highlighted:

- **Asset information** – the information about the asset that is required for effective lifecycle management and asset management
- **Asset information systems** – the information systems or databases that are use to inventory, manage, analyze, and report the asset information used by asset managers
- **Asset portfolio** – the range of assets and asset systems owned by the transit agency
- **Asset hierarchy** – how the asset portfolio is classified and segmented. It provides the framework for managing the asset management business processes. This guide provides an overall framework or asset classification.
- **Data definitions** – For data to be used consistently across the agencies, it is important to have unique definitions of the data items that are used for asset information. It also ensures consistency across applications and databases; for example, what constitutes a station in one database is a station in another.

Data Required

Successful transit asset management suggests transit agencies establish enterprise-wide policy and business requirements for the inventory process that results in a single inventory and data definitions for the various data items collected and maintained. The purpose is to answer the following questions: "Who is going to use the inventory and how would they want to use it?" and "What information does the agency need to support asset management processes?" This guide emphasizes focusing first on the user requirements (that is, determining "What information do I need to perform lifecycle management?") and then once the requirements are defined, determining the system solution or technical approach.[6]

Data Collection

For an inventory to successfully support the agency's asset management business processes, the inventory requires certain data. Collecting data for asset management can be costly, and priorities need to be established. Depending on the types of assets and the information, 100-percent samples and a complete inventory are not common or necessarily encouraged. The agency can evaluate the data that is currently available or identify data that can be collected as part of regular business processes (for example, during maintenance activities). For the data not available, the agency can develop a plan for making it available in the future. The plan can also outline how often the data will be updated. These decisions will all depend on having an appropriate level of resources to collect

[6] The manual recognizes that the data available and information systems that implement this will vary considerably between agencies, and that many agencies will be limited or constrained by their existing technology environment and, over time, be interested in system solutions that better enable their asset management.

and upkeep the data. Asset owners play a role in this process since they integrate asset data into their lifecycle management plans.

> As stated in the International Infrastructure Management Manual, "As a general rule, 80% of the data can be collected for half the total cost of 100% completeness."

Data Organization

The inventory process organizes the transit agency assets into asset classes and, within the classes, an asset hierarchy. This guide advises that assets are classified into maintainable units, which are organized into an asset hierarchy. This is because it is the maintainable unit to which the lifecycle management procedures (for example, inspections, predictive and preventive maintenance procedures, rehabilitation investments) are applied.

Agencies should establish their own asset hierarchies based on their asset types and business requirements. The 2011 *International Infrastructure Management Manual* defines an asset hierarchy as "a framework for segmenting an asset base into appropriate asset classifications. The asset hierarchy can be based on asset function, asset type or a combination of the two." Figure 3-5 illustrates, at a high level, the asset classification that this guide provides as a starting point for a transit agency.

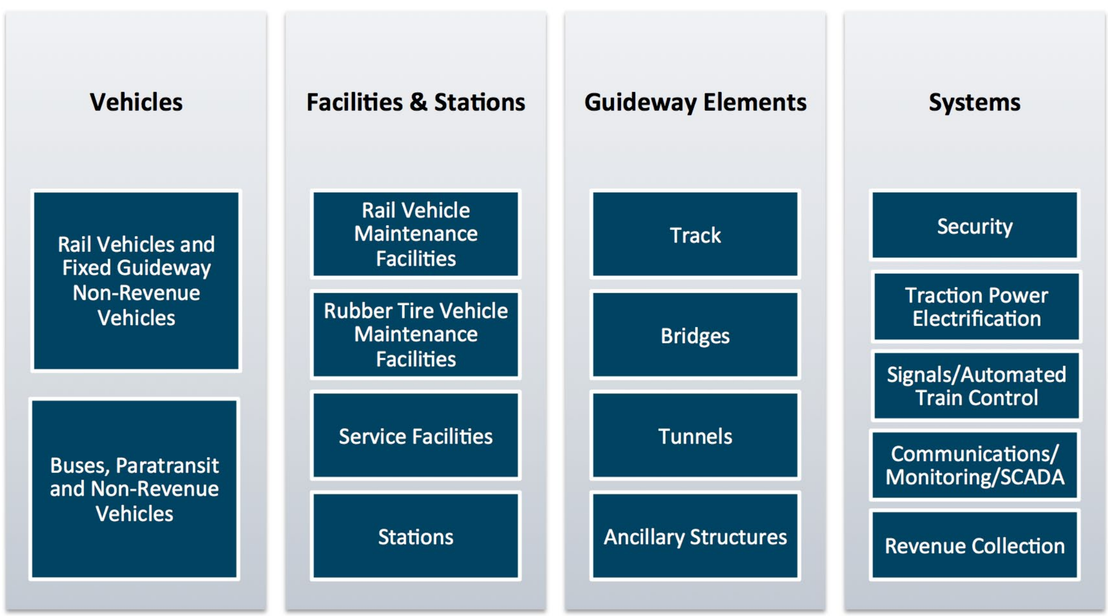
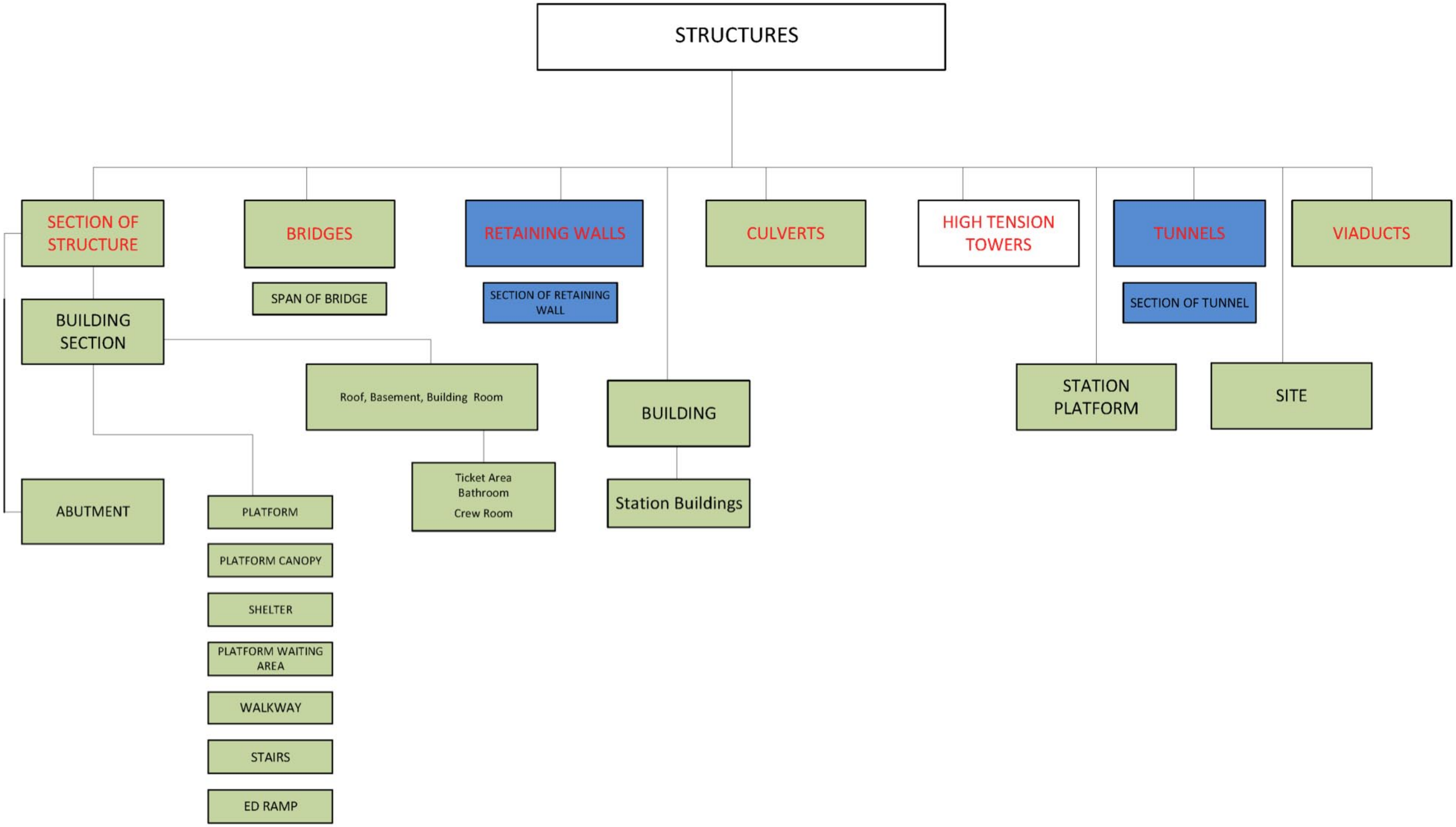


Figure 3-5 *High-Level Asset Class Hierarchy*

For each of the asset classes in Figure 3-5, this guide provides a starting point to develop lifecycle management plans (see *Asset Management Guide Supplement*). Figure 3-6 outlines a sample asset hierarchy for structures from New York's Long Island Rail Road.



Source: Engineering Assets Hierarchy, August 13, 2012

Figure 3-6 *Long Island Rail Road Sample Asset Hierarchy (Structures)*

Continual Improvement

An inventory that can be used to successfully support asset management relies upon established processes for maintaining inventory data. While the individual lifecycle management plans will define data requirements and include or reference the procedures that provide quality assurance for inventory data, the Asset Management Program Manager should have sound data administration processes in place so that the data is of good quality and appropriately supports the asset management business processes. Additionally, the Asset Management Program Manager and the asset owners should always be looking for more opportunities to cost-effectively collect more data when it is' supportive of the asset management business processes. To ensure this continual improvement, these processes have clear roles and responsibilities, schedules with milestones, a feedback loop, and quality assurance processes.

Transit agencies in the U.S. often address their asset inventory problems (for example, siloed departments and obsolete data) by procuring new software. They have a history of focusing on technical solutions without first addressing their business requirements and then defining how technology can enable them to be more successful.[7] In reality, current agency practices require considerable organizational and cultural change, in addition to technology solutions. Section 4, Asset Management Information Systems, provides guidance on addressing data integration and technology solutions.

Figure 3-7 depicts a snapshot of the Metropolitan Transportation Commission's (MTC') asset inventory reflecting sample track data from multiple agencies.

Operator	Category	Element 1	Element 2	Element 3	TCP Score	Unit of Measure	Quantity	Purchase or Next Replacement Year (Year)	Useful Life (Years)	Cost Per Unit (2007 $)
AAA	Railway/Track	Heavy Rail	Embedded	Tangent	16	Track Mile	86	2000	12	2,500,000
BBB	Railway/Track	Trackwork	Special	Ballasted Derail	16	Each	6	1972	15	25,000
BBB	Railway/Track	Trackwork	Special	Ballasted Derail	16	Each	2	1996	15	25,000
BBB	Railway/Track	Trackwork	Special	Ballasted Derail	16	Each	4	1997	15	25,000
BBB	Railway/Track	Trackwork	Special	Direct Fixation Derail	16	Each	1	2003	15	25,000
BBB	Railway/Track	Trackwork	Special	Ballasted Diamond	16	Each	1	1972	15	366,100
BBB	Railway/Track	Trackwork	Special	Ballasted Turnout	16	Each	100	1972	15	100,310
BBB	Railway/Track	Trackwork	Special	Ballasted Turnout	16	Each	169	1973	15	100,310
BBB	Railway/Track	Trackwork	Special	Ballasted Turnout	16	Each	11	1974	15	100,310
BBB	Railway/Track	Trackwork	Special	Ballasted Turnout	16	Each	7	1986	15	100,310
BBB	Railway/Track	Trackwork	Special	Ballasted Turnout	16	Each	13	2003	15	100,310
BBB	Railway/Track	Trackwork	Special	Direct Fixation Diamond	16	Each	2	1973	15	579,410
BBB	Railway/Track	Trackwork	Special	Direct Fixation Turnout	16	Each	3	1996	15	290,910
BBB	Railway/Track	Trackwork	Special	Direct Fixation Turnout	16	Each	34	2003	15	290,910
BBB	Railway/Track	Trackwork	Switch	Manual	16	Each	6	1974	15	20,000
BBB	Railway/Track	Trackwork	Switch	Motorized	16	Each	115	1972	15	35,000
BBB	Railway/Track	Trackwork	Switch	Motorized	16	Each	12	2002	15	35,000
BBB	Railway/Track	Trackwork	Switch	Motorized	16	Each	49	2003	15	35,000

Figure 3-7 *Snapshot of MTC's Asset Inventory*

[7] Most of the asset management strategy-related Requests for Proposals (RFPs) issued by U.S. transit agencies in the last two years are focused on the procurement of information systems.

Some of the benefits associated with having an agency-wide asset management inventory and information include the following:

- Accessible, consistent, and comprehensive information about an agency's assets at asset class and enterprise level. This inventory allows the agency to understand and communicate its assets' current value, age, and condition. Depending on what data is tracked, it can assist in monitoring warrantees, maintenance histories, and costs.
- Data integrity and accuracy can avoid the costs incurred from inconsistent, duplicate, and inaccurate data and can also improve an agency's credibility with internal and external stakeholders.
- Data are organized and structured in a way that it can support all asset management business processes. This means that appropriate levels of information are available and accessible to the right people at the right time.
- Accurate, current data to support data-driven, transparent decision making, which can improve an agency's decision making and stakeholder relations.

Asset management inventorying success factors:

- Transit agencies establish enterprise-wide policy and business requirements for the inventory process that results in a single inventory and data definitions for the various data items collected and maintained.
- Inventories have established "owners" who are responsible for the management and quality of the data.
- Agencies establish their own asset hierarchies based on their asset types and business requirements.

Key implementation principles associated with managing the data associated with an asset inventory include the following:

- There is no "one-size-fits-all" approach; the data collected supports the established asset management policies and goals. It also reflects any other data needs throughout the organization. For example, an asset inventory can be used to identify and locate assets to support the maintenance and operations of the assets. It can provide financial data in order to calculate maintenance and replacement costs. For more mature asset management organizations, the asset inventory may be used to review an asset's maintenance history and costs to support lifecycle optimization and the probability and consequence of asset failure for risk management.[8]
- Applying sound data administration practices is a fundamental building block for maintaining an asset inventory and is a part of normal business processes. An agency has documented processes in place to ensure that the data stored in the inventory is current, correct, complete, and consistent. Data

[8] *International Infrastructure Management Manual*, Chapter 2.4.

collection and validation can sometimes be most economically collected as part of day-to-day operation and maintenance activities.[9] The *International Infrastructure Management Manual* states that data collection is the largest workload component of an asset management program, often constituting 80 to 95 percent of the setup costs. (Note: Many systems have the ability to validate data when it is entered.)

- There is no duplication of inventories; the expectation is that developing and maintaining an inventory is an enterprise business process. Multiple processes and other systems will draw on and require inventory information, including accounting and the FTA's National Transit Database reporting. If these reside in other databases, a process to replicate the data from the enterprise source—and only that source—may be necessary; however, an appropriately customized data architecture eliminates this need. This guide recognizes that many agencies have data in multiple locations and at times with differing data definitions. Agency asset management plans provide the direction to address this and migrate to enterprise inventory solutions that eliminate duplicate databases and inconsistent data definitions. A key to addressing the challenges associated with multiple inventories is to have a unique asset identifier associated with every asset.
- Managers in the organization ensure accountability for maintaining this asset data. Accountability may be tied to the quality of the data or to the asset performance (which is indirectly associated with the data).

[9] *International Infrastructure Management Manual*, Chapter 2.4.

Case Study

Valley Regional Transit (VRT) – Meridian, Idaho

Relevance of Case Study

Valley Regional Transit (VRT, formerly known as VIATrans) has demonstrated how multiple smaller transit agencies and transit providers can work together to develop regional partnerships to improve transit asset management through a centralized asset inventory.

Agency Overview

VRT was formed in 1998 to serve as the regional public transit authority for Ada and Canyon Counties in Idaho. VRT provides ValleyRide bus service to the city of Boise, along with Ada and Canyon Counties. VRT owns the ValleyRide bus system and manages the system assets. The agency also manages contracts for service in Boise/Garden City, Nampa/Caldwell, and inter-county routes. The entire ValleyRide system comprises 26 bus routes and paratransit services. The

VRT fleet includes 6 vans, 58 buses, and 11 support vehicles. In FY 2011, the bus system provided 1.37 million one-way trips and 40,825 paratransit rides.

Asset Management Implementation Path

In assessing its needs with respect to asset management, VRT established that it needed an improved system for tracking its asset inventory. In particular, the agency needed an improved system for prioritizing investment needs, supplementing the functionality provided by the existing accounting, work-order processing, and inventory tracking systems. Realizing that other local agencies faced similar challenges, VRT formed a regional partnership to implement a transit asset management system, and led the effort to apply for an FTA grant on behalf of the partnership to fund the initiative.

In establishing a regional partnership for improving asset management, VRT first approached stakeholders with common goals and similar assets. These stakeholders included Boise State University and its shuttle system, Ada County Highway District – Commuteride division, and Idaho Transportation Department, which distributes federal funds to a number of Idaho transit providers. Regular stakeholder meetings are held to provide each partner with the opportunity to participate in the process.

As part of the process, each partner organization agreed to inventory its assets and record asset conditions. VRT plans to evaluate the quality and consistency of the data in order to determine the information that still needs to be collected. Methods for future data collection will be developed to ensure that all of the organizations are using a consistent approach and have comparable data. The combined assets of the participating organizations include transit buses, paratransit vehicles, vanpool and social service agency vans, university shuttle buses, support vehicles, park & ride lots, bus shelters and benches, operations and maintenance facilities, and transit centers. Given the range of different assets in the inventory, it is important that the participants continue to be active in the planning process to ensure that the resulting system is flexible enough to account for each organization's needs.

Ultimately, VRT and its partners plan to develop an asset management system in which all of the collected data will be stored and analyzed at an individual and regional level. VRT is particularly interested in developing a capability for analyzing which asset investments are the "best" investments.

Benefits/Outcomes

The Regional Capitalization Plan is expected to establish a methodology for future efforts to improve data collection, analysis, and prioritization models for

Idaho transit agencies and providers. This plan will help individual organizations to develop asset management strategies while providing an improved capability for regional analysis. The plan also has the long-term potential for developing a protocol for sharing assets between agencies, which could yield further efficiency gains. By pooling resources across multiple organizations, the partner agencies are implementing state of good repair practices and systems more cost effectively than a single agency acting alone.

Sources and Other Resources

Information provided by a senior contact at VRT.

Role of Condition Assessment and Performance Monitoring

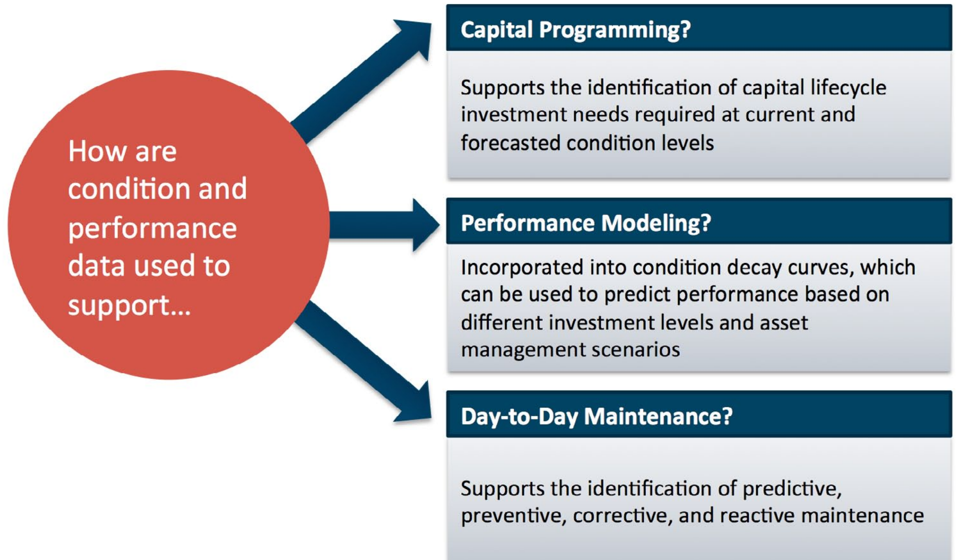
Condition assessment is the process of inspecting the asset to collect data that is used to measure condition and performance. The condition assessment process involves regular inspections that evaluate an asset's visual and physical conditions (for example, structural issues, faulty components). This process addresses risk, ensures the asset can meet its level-of-service requirements, and provides information from which assets can be managed across their lifecycle. Condition assessment and performance monitoring can result in the following activities:

- Address immediate issues by completing reactive maintenance activities.
- Proactively identify any predictive and preventive maintenance or rehabilitation necessary.
- Collect condition and performance data for scenario evaluation and performance modeling.

There are varying degrees of consensus and industry standards of practice for inspecting and monitoring condition. In many cases, only a sampling of the asset class needs to be inspected. The size of this sample and frequency of inspection should be directly related to the level of risk associated with this asset. The condition measure provides indicators of the likelihood that the asset will perform as intended. There are some condition inspection and assessment requirements that are mandatory, which means that they are required by law or as requirements from federal or other funding agencies. See the *Asset Management Guide Supplement* for these and other asset class-specific inspection guidelines.

Condition assessment data can be used to support asset management-related decision-making activities, including capital programming, performance modeling, and day-to-day maintenance (see Figure 3-8).

Figure 3-8
Condition Data Requirements of Different Business Processes

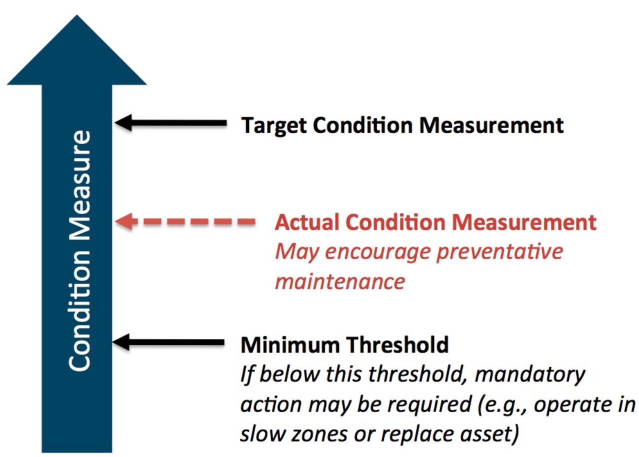


Establish Target Condition and/or Performance Target(s)

This target is a singular measurement or a composite measurement. It can be complex, but it involves measures of the physical condition of the asset that provide indicators of its likelihood of achieving the asset's level of service requirements. These targets are usually set as standards—some of which can be mandatory (involving a pass or fail rating). These measures are indicators of the structural and functional condition, which relate to the ability to meet level-of-service objectives that are set.

In addition to establishing condition and performance targets, it is also important to establish the minimum tolerable condition of the asset. This refers to a minimum threshold below which a measured condition would result in a mandatory action by the asset owner to remedy the situation. For example, structural inspection of track or structures can result in establishing mandatory slow zones. Figure 3-9 depicts how an asset's condition measure can be evaluated against a target condition measure and a minimum threshold.

Figure 3-9
Condition Assessment and Performance Monitoring Process



Establish Condition Assessment Process and Measurement Procedures

The condition assessment process involves inspection and data collection to monitor and predict performance. The methods and procedures that are used and the frequency of the inspections should be specified as part of the lifecycle management plans. These will be specific to each asset class or, potentially, to an individual asset. The condition assessment process includes the following:

- **Specifying the Condition and Performance Measures** – This is technically driven and, in some cases, specified by laws or industry standards. Condition and performance measures support the other asset management business processes.
- **Procedures for Data Collection** – The approach to collecting the data includes the following:
  - Sampling requirements – These address how many of the assets or subcomponents require inspection.
  - Data collection frequency – This addresses how often the inspections should occur. Triggers for a condition inspection may be based on a time or mileage interval, criticality or risk assessment, or it may be based on a performance trigger (for example, a bus with a skyrocketing mean time between failure metric).
  - Inspection approach – For many asset classes, condition inspections can require appropriately trained and credentialed staff. Additionally, there is increasing interest and ability to substitute a visual or manual inspection with technology-enabled monitoring. Examples include using sensors to monitor structural conditions and switch performance. Moreover, some inspection data may be collected through day-to-day maintenance processes.
  - Quality assurance process – These are the processes used to verify the data and ensure quality. Quality assurance processes may require random data checks or formal audits.
  - Training – This is an important part of quality assurance for condition assessment and ensures that condition is being measured consistently and accurately.

These methods need to be specified as a defined procedure in the appropriate lifecycle management plan to ensure quality. The *Asset Management Guide Supplement* describes transit industry standards of practice for each major asset class.

Some of the benefits associated with having an asset management condition assessment and performance monitoring include the following:

- Improved ability to proactively invest in preventive maintenance activities to minimize premature asset failure (risk management) through targeted condition inspections and better use of condition data
- Improved capital and operations and maintenance budget forecasting based on more-accurate predictive modeling of an asset's condition (based on improved historic and current asset condition data)
- Refined maintenance strategies (based on improved understanding of an asset's condition throughout its lifecycle), which can improve resource allocation and asset performance
- Avoidance of premature asset failure (based on targeted condition inspections), which can improve overall reliability and cost-effectiveness goals
- Avoidance of premature asset replacement based on condition data that demonstrates the asset is meeting its level of service requirements

Asset management condition assessment and performance monitoring success factors:

- Condition inspection/monitoring program in place for all critical assets, prioritized by usage rate, risk, and other criteria outlined in the lifecycle management plans. Condition is evaluated consistently across all asset classes.
- Condition data collected supports the appropriate business processes (for example, lifecycle management, capital programming).
- Quality of the data is consistently evaluated and improved upon.
- New technologies for condition assessment and performance monitoring are integrated when cost effective.
- Condition inspections/monitoring support regulatory requirements.

Key implementation principles associated with the establishment of an asset management condition assessment and performance monitoring include the following:

- Selection of an asset class' condition inspection approach depends on the costs and risk factors associated with that asset. Additionally, the inspection and measurement approach considers industry standards (see the *Asset Management Guide Supplement*) and how the information will be used. The extent to which condition inspections are conducted depends on the following factors:
  - The criticality of the asset (If the asset fails, what are the consequences? How safety-critical is this asset?)
  - The type, usage, and age of the asset (Is the asset close to the end of its useful life, so more likely to fail?)
  - The asset environment (Is the asset exposed to environmental conditions that might cause faster deterioration?)

– The asset usage (How much is this asset used and how well is it operated?)
– The ability of the agency to improve the asset's performance through maintenance activities
– The ability to access the assets (Is the asset underground or in another remote location?)
– The past performance of the assets reflecting level of deterioration

"[The agency] recognized the importance of identifying assets and their components that are most critical. The risk of these component failures is combined with a condition rating to develop an overall risk score. The outcomes of this risk score system include: Items with low scores force increased frequency of evaluation; failure of components in high risk area forces immediate inspection of all similar components; and if any accelerated aging is identified, all components of the same type are replaced."

– U.S. Transit Agency Manager
(Source: 2011 Parsons Brinckerhoff Survey)

- Condition inspections include the manufacturers' recommended preventive maintenance tasks; however, modifications can be developed and applied based on the condition and age of the asset, the particular challenges of the duty cycle, and the unique environmental conditions faced by each agency and asset. Manufacturers typically provide established inspection standards based on asset usage. Inspections can be adapted to an asset's condition to emphasize particularly challenging asset components, but the manufacturers' recommended preventive maintenance program forms the foundation to the inspection program.

The condition value ratings for individual (sub) components can be weighted based on the component's percentage contribution to the asset's total lifecycle capital costs to yield a "comprehensive," weighted average measure of that asset's overall condition.

- Condition is assessed in an established, consistent way. Approaches to obtaining condition data may include the following:
  – Periodic assessment of all assets
  – Statistical sampling based on asset attributes
  – Random sampling of asset class without consideration of asset attributes
  – Ad hoc data collection to support miscellaneous needs and unforeseen issues (for example, earthquakes)
- The measure (or rating) assigned to an asset's condition is intended to inform investment decisions that will affect the asset's performance. The approach to measuring an asset's condition is established for each asset class and its components. Consistency in evaluating the assets can be attained by ensuring team members work closely to ensure conformity in the interpretation

and application of the condition measurements and by utilizing the same condition assessment process and definitions for all inspections.

- The assessment of the overall physical condition for individual assets is comprehensive—covering each of the asset's major components and subcomponents. A comprehensive evaluation is ensured by developing detailed inspection forms (ideally in electronic form) allowing inspectors to rate physical conditions for a wide range of asset components and subcomponents.
- Since condition inspections can be time- and labor-intensive, other data sources can be used as a proxy measure of an asset's condition, which will ultimately be used as a predictor for an asset's performance. Total asset usage (for example, miles or hours), subcomponent maintenance and replacement data, and asset age are supporting data points that can provide similar insight as condition data.

Long Beach Transit (LBT) provides public transportation to Long Beach and 11 other cities, incorporating a fixed route service, free shuttle service, demand responsive paratransit, water taxis, and community special services. An important aspect of LBT's asset management approach is that it is establishing a measure of asset criticality to help prioritize asset management decisions. LBT's asset criticality measure is being determined based on the likelihood of failure (using data on percentage of useful life consumed) and severity of failure (measured in terms of impact to people, environment, costs, and operations). At the conclusion of the agency's inventory development process, LBT expects to obtain data on condition and criticality for each of its vehicles and fixed assets, and will use this data to prioritize future maintenance projects.

Case Study

MARTA: Condition Assessment and Performance Monitoring

Relevance of Case Study

Demonstrates successful implementation of an agency-wide asset management program with policy, plans and processes that effectively utilize trusted and accessible asset data. The cornerstone of the program is a well-structured asset inventory that contains asset-specific priority and condition codes, detailed asset information and is kept current through the use of routine inspection and maintenance procedures.

Agency Overview

The Metropolitan Atlanta Rapid Transit Authority (MARTA) provides heavy rail, bus, and paratransit (mobility) services to the Atlanta region. MARTA carries approximately 500,000 passengers daily. MARTA's assets include the following:[10]

- 48 miles of rail service (120 miles of track)
- 338 rail vehicles
- 3 rail yards
- 38 rail stations
- 590 buses
- 3 bus maintenance facilities
- 175 paratransit vehicles
- 450 non-revenue vehicles
- 1 non-revenue vehicle maintenance facility
- 100+ ancillary buildings

MARTA's rail system began operation in 1979, and many assets are now approaching the end of their expected useful life. Furthermore, finances of the agency, which are largely dependent on local sales tax receipts, are severely strained. Thus, determining how to best use available funds to maintain a state of good repair is a significant issue for the agency.

Asset Management Approach

MARTA uses a transit performance-based definition of state of good repair as a "condition of an asset where the asset, at a minimum, is capable of delivering the required performance safely and reliably for a predetermined period of time." By this definition, as of June 2010, approximately 97 percent of MARTA's assets were classified as being in a state of good repair.[11]

MARTA's investment in assets including their acquisition, operation, maintenance, renewal, and disposal is guided by the desire to provide best possible service to the riding public with safety at the top of the list. This means fewer service interruptions, increased customer satisfaction and reduced operating and maintenance costs. To manage its assets, MARTA uses a "systems approach" with an established mission, vision, plan, policy, and procedures that are integrated with their normal business processes. Their asset inventory hierarchy, asset-specific inspection and maintenance policies are tied to system performance. An Enterprise Asset Management (EAM) system is used to track data related to asset inventory,

[10] *Transit Asset Management Practices – A National and International Review*, June 2010.

[11] *Transit Asset Management Practices – A National and International Review*, June 2010.

inspection, and work performed. MARTA's asset inventory, which they refer to as asset breakdown structure (ABS), comprises 16 major asset categories. For each category, the ABS identifies three additional subcategories: systems, components, and types. For some asset types, inspection and maintenance policies are highly formalized. For instance, for rail cars MARTA developed the Life Cycle Asset Reliability Enhancement (L-CARE) program, which details the maintenance actions to be performed over the lifecycle of a rail car for 11 different car systems. MARTA is consistently developing asset management strategies to efficiently manage inspection and maintenance data for all of its critical assets.

MARTA periodically performs comprehensive condition assessments of its assets. These assessments provide additional information, which can inform maintenance, rehabilitation, and replacement needs over time. For example, MARTA performs a visual inspection of its tracks twice per week and uses a track geometry car for each section of track one to two times per year. The data is stored in the EAM system). Data for more than 53,000 assets is stored in the EAM system and MARTA's intent is to integrate all relevant data electronically into their short- and long-term Capital Improvement Planning process.

Benefits/Outcomes

MARTA's asset management initiative has derived the following:

- Although MARTA's capital program was reduced from $386M to $185M over a four-year period, MARTA has been able to maintain a high percentage of its assets in a state of good repair. This results from having better information to target available funds where they are most needed, as well as from having the information needed to make the case for spending to maintain a state of good repair. Now, approximately 85 percent of the capital program is being used to address state of good repair needs—a significant increase.
- More-accurate estimates of its investment needs by performing periodic condition assessments and representing assets at the system, type and component level. MARTA's Office of Maintenance of Way tracks all wayside rail system assets through their EAM system. This includes description, location, in-service date, inspection cycles, cost, maintenance history, priority, and condition code. This information flows directly into Capital Reports, which are then used by stakeholders to make investment decisions. Within the Office of Rail Car Maintenance, the expected and remaining useful life of rail cars is tracked not just for the railcar as a whole, but for each of the major systems of the car, which means performance and costs can be managed more effectively. MARTA, a 33-year-old system, is routinely achieving 98 percent rail on-time performance. This high level of performance is attributed to many things, but at its base is a well-maintained rail fleet, wayside systems, and infrastructure.

- MARTA's efforts to improve its asset management systems and approaches have made the agency more competitive in its efforts to obtain FTA state of good repair grants, and resulted in MARTA's winning several grants to provide needed funds.
- Trusted and accessible asset data has improved MARTA's ability to demonstrate compliance with local, state, and federal regulatory requirements, respond to audits and to support transit industry initiatives with peer agencies, consultants and the supply chain.
- The benefit of this well-structured asset management program is better overall agency performance. This includes improved service, safety, and environmental performance as well as optimized return on investment, more efficient use of resources (labor and non-labor), enhanced customer satisfaction and a positive agency perception.

Sources and Other Resources

Information provided by a senior contact at MARTA.

Role of Lifecycle Management Planning Process

This guide recommends defined processes and procedures for the lifecycle management of each asset class and, as applicable, for individual assets—documented in a lifecycle management plan. A lifecycle management plan documents the costs, performance, and risks associated with an asset class throughout its life. As shown in Figure 3-10, good data regarding costs, performance, and risk throughout an asset's lifecycle can improve asset performance because of better-informed decision making.

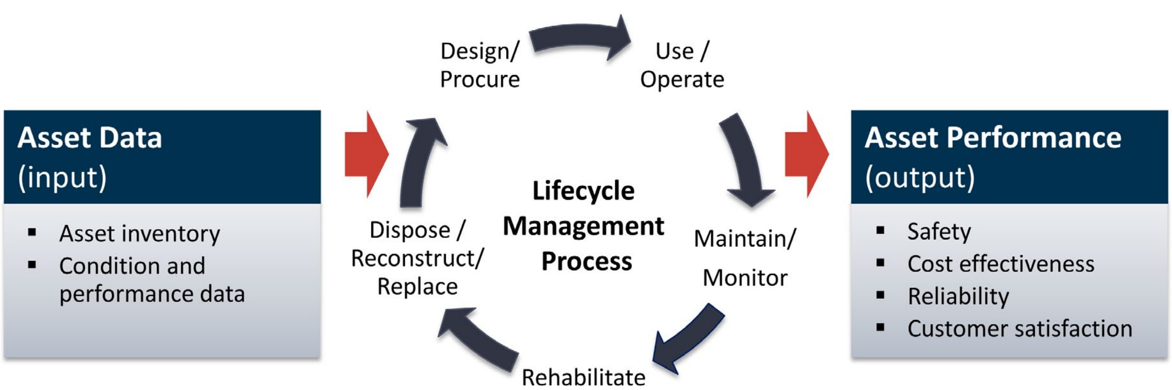


Figure 3-10 *Lifecycle Management (Using Asset Data to Improve Asset Performance)*

The contents of a lifecycle management plan will vary depending on the level of asset management maturity for the asset class. While a less mature lifecycle management plan will focus solely on developing an asset inventory, a more mature lifecycle management plan will include asset class–specific policies, condition assessment, and performance monitoring, level-of-service requirements, procedures and plans for preventive and reactive maintenance, and rehabilitation and replacement timing and costs. Ideally, a lifecycle management plan is created during the asset's design/procurement stage to ensure it is designed and/or manufactured in a way that considers the asset's performance requirements and total cost of ownership. A lifecycle management plan can be used to ensure that the performance expectations of the asset are understood and fit within the agency's broader goals and performance objectives, and that all investment decisions are transparent and well communicated. Table 3-3 provides the recommended contents of a lifecycle management plan.

Examples of asset class specific policies include:

- Buses should be rehabilitated when in service for 6 years and then replaced when in service for 12 years.
- Maintenance facilities should be replaced after 40 years in service (or 70 years if rehabilitated).
- 95 percent of elevators should be available at any time.

Some of the benefits associated with the use of lifecycle management plans include the following:

- Improve the performance of assets throughout their lifecycle while ensuring the most cost-effective investment strategies.
- Minimize the risk of failures throughout the system.
- Make data-driven, informed investment decisions within an asset class and at the enterprise level.
- Improve internal communications by requiring cross-department coordination throughout the asset's lifecycle.

Table 3-3 *Lifecycle Management Plan Contents*[12]

Section Name	Contents Description
Roles & Responsibilities (Who is responsible for this asset's lifecycle management activities?)	Outlines roles, responsibilities, and accountabilities for the asset's lifecycle management, including the "Asset Owner."
Asset Inventory (What assets are included in this lifecycle management plan?)	Introduces this asset class, including: • Inventory process overview • Asset risk assessment (overview of criticality) • Challenges the agency faces with maintaining asset class
Condition Assessment & Performance Monitoring (How will the asset class' performance be measured and monitored?)	Outlines the asset class' current condition and references the documented asset class-specific approach to condition assessments and performance monitoring. This includes outlining when the asset should be inspected, how inspections will be conducted and condition measured, and what actions should be taken based on the rating assigned.
Preventive Maintenance Plan (What activities can be proactively completed?)	Outlines the predictive and preventive maintenance approach[13] to maximizing the performance and minimizing the costs of this asset class. This describes the resources needed (costs, staffing, materials, etc.) and links to performance.
Rehabilitation and Replacement Plan (What capital investments are needed?)	Outlines the rehabilitation and replacement approach[14] to maximizing the performance and minimizing the costs of this asset class. This describes the resources needed (costs, staffing, materials, etc.) and explains and links to performance.
Asset Policy and Strategy (What are the asset management goals for this asset class?)	Outlines any policies and strategies related to this asset class. It also explains how the asset's lifecycle management activities support the broader asset management policies and goals (including level of service requirements and sustainability outcomes).
Asset Lifecycle Management (What are investment activities necessary for maximizing the performance of this asset?)	Outlines all lifecycle management activities, including considerations and strategies regarding procurement, warrantees, operations, maintenance (preventive and reactive), rehabilitation, and disposal. This section identifies the total cost of ownership for this asset class, with the focus on lifecycle management activities that maximize the asset's performance (including sustainability outcomes) while minimizing risk and costs.
Capital Programming & Operations and Maintenance Budgeting (How will asset management support capital programming and operations and maintenance budgeting?)	Forecasts the capital and operations and maintenance budget needed to address the lifecycle needs of this asset class. The budgeting timeframe should match the agency's overall capital and operations and maintenance budgeting timeframes.
Performance Modeling (How will asset condition data support scenario evaluation?)	Identifies how available data can be used to evaluate how well an asset class is achieving its level of service, sustainability, and other performance goals. Historic data (compiled into decay curves) and current data can be used to monitor performance over time and forecast how different funding levels can impact performance in the future.
Continuous Improvement (How can we ensure we continue to get better at managing this asset?)	Outlines how the asset owner should be monitoring the performance of this asset class to ensure that this plan is being followed and, ultimately, the asset class' performance is being maximized. This section should capture any lessons learned associated with managing the lifecycle of this asset class. Additionally, it should reflect the process for maintaining the lifecycle management plans.

[12] Lifecycle management plan contents will vary depending on the level of asset management maturity associated with the asset class.

[13] This section may be developed based on the manufacturer's guidelines; however, adjustments should be made reflecting past experience and local requirements.

[14] *Ibid.*

Lifecycle management plan success factors:

- Asset investments consider the benefits and trade offs associated with capital versus operations and maintenance solutions.
- Lifecycle management plans provide a clear link to agency goals and performance expectations.
- Lifecycle management plans are managed by the asset owner; however, they reflect input from throughout the agency.

Key implementation principles associated with lifecycle management include the following:

- Lifecycle management plans can be developed for the most-critical assets first, and details can be added as the agency's asset management maturity increases.
- When possible, require the manufacturer/contractor to include the lifecycle management requirements as part of the asset's procurement/creation. An agency's operating environment and funding availability may require something different; however, the manufacturer can provide a useful starting point for effective lifecycle management practices.
- Lifecycle management plans are developed with input from all departments that are involved in that asset's lifecycle. Represented parties likely include procurement, engineering, operations, maintenance, and capital planning.
- While many parties will likely provide input into the plan, the asset owner is responsible for coordinating the development and upkeep of it.
- Lifecycle management plans are continually updated to reflect changes in the operating environment, condition assessment technologies, and manufacturer guidelines.
- Lifecycle management plans are made available on an agency's intranet (or other shared file location) so management and staff can access the information as needed.
- An agency evaluates cost, risk, and performance to determine the optimal amount of preventive maintenance for an asset. There is an optimal amount of planned maintenance for assets that minimizes the cost of planned versus reactive maintenance. This evaluation requires experience, understanding of asset behavior, repair methods, and, ideally, the use of analysis tools.
- Evaluate the costs, risks, and performance data of all asset management lifecycle activities associated with an asset to determine the optimal investment strategy. Table 3-4 outlines these lifecycle activities.

Table 3-4

Potential Lifecycle Activities

Lifecycle Activities	Activity Description
Create or Acquire	New assets or created or procured to increase capacity, meet current demand, and address performance objectives
Do Nothing	Assets are operated until they fail or can no longer deliver the required performance
Examine Operational Procedures	Operational management is changed to manage stress on the asset, such as reducing a vehicle's exposure to hills
Routine Maintenance	Conducted to keep assets in a serviceable condition and address performance requirements
Renew or Replace	Replace an asset when it is insufficient to keep the asset serviceable or when it is more cost-effective to replace
Upgrade	Improve existing asset to address performance requirements
Dispose	Decommission and/or demolish and/or recycle and/or sell obsolete assets

Source: Adapted from Ciria, "Whole-Life Infrastructure Asset Management: Good Practice Guide for Civil Infrastructure," 2009.

Cross-Asset Planning and Management

Cross-asset planning and management refers to agency-wide processes for managing performance through the capital planning and budgeting process across the portfolio of transit assets. It is addressed in a transit agency's capital planning and operations and maintenance budgeting processes. A transit agency's capital plan and operating budget are the mechanisms through which competing goals and objectives are assessed and implementation priorities established through funding decisions.

A mature asset management process involves integrating lifecycle management plans from the different asset classes to do the following:

- Communicate asset condition and the resources required to meet level of service objectives to policy-makers, stakeholders and customers
- Allocate available funds in a performance-based budgeting process that considers the level of service that various resource allocation decisions allow the agency to purchase with the funds they have available

This guide emphasizes the role for asset management in providing information that can better link budget decisions to performance. Agencies typically develop one-, two-, or five-year capital programs and one- or two-year operations and maintenance budgets on an annual basis. More mature asset management organizations may use scenario evaluations as a tool through which transit agency boards and the general manager can consider "what if" scenarios in terms of the impact on performance of different levels of investment and budget allocations. Cross-asset planning and management business processes are outlined in Figure 3-11.

Figure 3-11

Cross-Asset Planning and Management Business Processes

Cross-Asset Planning

Capital Planning & Programming
- Optimizes how and when capital funds are expended based on consistent, reliable data
- Reflects "top-down" guidance from agency leaders and "bottom-up" forecasted capital needs

O&M Budgeting
- Optimizes funds expended based on LOS goals
- Relies on performance-based decision-making reflecting on lifecycle management plan input

Performance Modeling
- Applies analytical tools that use reliable condition and cost data to model performance under different investment scenarios

Role of Capital Planning and Programming

The capital planning and programming process determines how and when capital funds are expended. It is typically an annually recurring process by which a transit agency's capital needs are specified as improvement projects that are prioritized, budgeted, and scheduled over a multi-year time period. More often than not, an agency's available funding is insufficient to cover identified capital needs, so the agency has a process for selecting the highest priority projects. The intent is to prioritize the capital projects that best address the agency's goals, which typically involve replacing worn out assets, reducing cost, and enhancing performance. Transit agencies have been prioritizing their capital needs for as long as they have been in existence; this guide addresses how to incorporate asset management into existing capital programming processes. In general, the business model outlined in this guide conforms to best practice, which is to link outcomes—the performance of the agency—to the planning, programming and other decisions that are made.

> Capital programming that utilizes asset data to drive decision making will contribute significantly towards an agency's performance management focus.

Capital programming processes typically involve input from two directions:

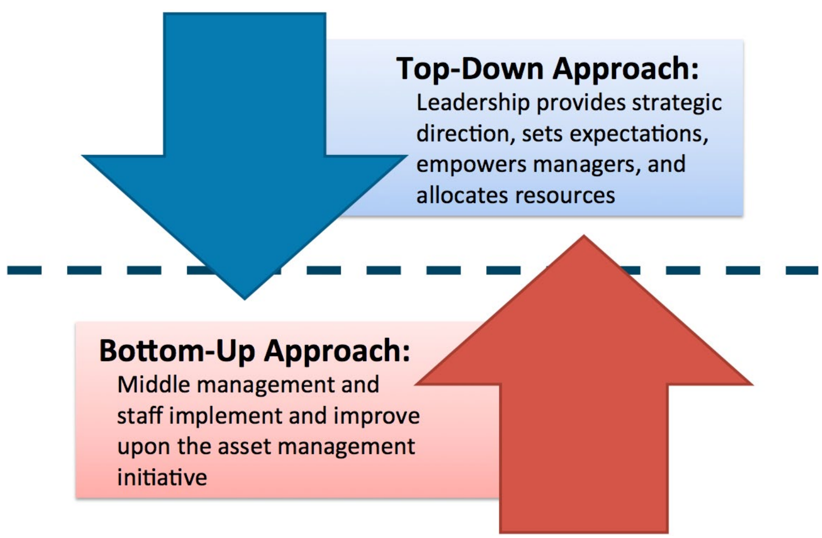
- **Top-Down** – The leadership team decides the high-level priorities and sets policies to address these. In order to support their asset management goals, it is important for the leadership team to consider the relationship between the allocation of capital dollars to existing assets' investments that address performance reliability and other asset management–related performance objectives (as opposed to capital enhancements or expansion investments). Best practice involves scenario planning that considers the impact on performance of alternative programmatic allocations of funding. Additionally, best practice considers a risk assessment across the entire asset portfolio. Assets with the highest risks (typically related to assets whose failure would lead to safety issues or significant performance impacts). Agency leadership may also provide direction to focus the capital program on sustainability investments.

- **Bottom-Up** – Asset owners and staff who use the assets provide input on their forecasted capital needs. Asset management best practice suggests that this information comes from lifecycle management plans that are data driven. Inputs from the lifecycle management plans include detailed cost and schedule forecasts on the capital renewal and replacement needs specific to each asset class. Additionally, asset owners likely need the ability to use their own discretion regarding how dollars are allocated within the asset class, especially if their asset class requires significantly higher reactive maintenance funds.

This balance of incorporating top-down asset management focus with bottom-up capital needs information to prioritize a capital program is characterized in Figure 3-12.

Figure 3-12

Asset Management-Focused Capital Program Prioritization Inputs



The lifecycle management plans specify the comprehensive capital needs associated with meeting the desired level of service objectives; however, it is' unlikely that funding is available to address all of these needs. Prioritizing across all of the asset classes is one of the more complicated aspects of the capital programming process. There are two types of prioritization decisions:

- Allocation between asset classes
- Allocation within the asset classes

For the former, the Capital Programming Manager (likely with input from the executive team) makes prioritization decisions based on the criticality of the asset class, how important it is towards supporting the agency's level of service goals, and the risk of not investing. For the latter, lifecycle management plans prioritize capital investments within an asset class, and this feeds directly into the capital programming process.

The following are important cross-asset prioritization considerations:

- **Consider programmatic policies and goals** – The prioritization of capital needs focuses on outcomes and may need to consider how the capital needs are packaged. For example, an agency may invest in all of their stations' stairwells to support a safety goal instead of upgrading all assets within one station.
- **Identify mandatory projects** – Before undertaking any prioritization process, a handful of projects can likely rise to the top of the list. Examples of these mandatory projects may be projects with committed funding, projects that will satisfy a safety, performance, or other mandate, and projects that the general manager is requiring.
- **Understand project dependencies** – Some projects may need to be completed before another can begin (for example, procuring articulated buses before facilities are retrofitted to accommodate larger vehicles). Others may not be useful unless done in conjunction with other projects (for example, upgrading fare gates may also require the replacement of all ticket vending machines).
- **Consider realistic project timelines** – Staff availability, procurement schedules, and right-of-way access may limit the ability of an agency to invest in assets up for renewal or replacement. It is important not to prioritize capital needs if it is not realistic to spend the funding in the budgeted year.
- **Consider the interconnected nature of transit assets** – In many cases, it may make sense to replace or rehabilitate assets before their lifecycle management plan dictates. This may be because of a bulk procurement opportunity, labor availability, or geographic proximity to other investments. Lifecycle management plans address these types of considerations.

On an annual basis, [this agency] uses data from its enterprise asset management system to update its 10-year Capital Improvement Plan (CIP). [This agency] has issued guidance for development of the CIP that specifies the decision-making criteria, including existing asset conditions, maintenance costs, remaining service life, and lifecycle costs for proposed capital project alternatives.

– U.S. Transit Agency Manager
(Source: 2011 Parsons Brinckerhoff Survey)

Some of the benefits associated with incorporating asset management more effectively into an agency's capital programming process include the following:

- State-of-good-repair investments are considered on the same footing as system development or expansion. Lifecycle cost, risk, and performance data are incorporated into the agency's existing capital programming process to make objective, informed cross-asset investment decisions.
- Internal and external stakeholders are provided with clear performance-based justification for funding decisions. This process helps communicate the link between service outcomes or performance and funding levels. Capital programming decisions made in conjunction with operations and maintenance cost estimates can help to reduce the overall lifecycle costs of assets.

Key implementation principles associated with establishing an asset management-focused capital programming process include the following:

- The capital program reflects input from the executive team, management, and asset owners.
- When possible, asset owners communicate the potential negative consequences, or risks, associated with not prioritizing their asset class' needs. The more clearly an investment can be tied to an agency goal or performance objective, the more compelling the case will be.
- While information systems can support the capital program prioritization process, tools cannot replace the multidisciplinary discussions that are required for effective capital programming.
- If scenario evaluation is available, the capital programming process can incorporate findings associated with the relevant analysis and discussions.
- The capital program and operations and maintenance budget are developed in a coordinated, interactive fashion at the same time each year. This allows for the consideration of implications to the operations and maintenance budget when the capital program funding is increased or decreased (and vice-versa).
- Ideally, an agency can show how each capital investment supports its goals at any time during a capital project's lifecycle. For example, the replacement

of track and its subcomponents may allow for trains to operate at a higher speed, which may have a direct impact on agency-wide goals like on-time performance. Ultimately, this kind of performance measurement demonstrates the value of the investment.

Capital planning and programming success factors:

- Shared responsibility, including the executive team, management, and asset owners, in developing the capital program
- Established policy for the agency leadership to make programmatic decisions (for example, what percentage of the budget should be focused on state of good repair needs versus expansion needs)
- Complete, up to date, and accurate lifecycle management plans that outline the agency's assets' capital needs
- Simple, quantifiable, agreed upon prioritization criteria that demonstrate the link between capital investments and agency outcomes. These criteria will provide a transparent, consistent way to evaluate state of good repair needs across all asset classes

Case Study

Regional Transportation Authority (RTA) – Chicago, IL

Relevance of Case Study

The Regional Transit Authority (RTA) performed a comprehensive assessment of the condition of transit assets in the Chicago area, and is developing a decision support tool to help prioritize state-of-good repair investments. RTA's experience illustrates the importance of developing a structured approach for prioritizing state-of-good-repair investments.

Agency Overview

RTA was created in 1974 to provide public transportation in the surrounding Chicago and the six-county northeastern Illinois regions surrounding Chicago. Today it oversees the third-largest public transportation system in the U.S. The service boards are as follows:

- Chicago Transit Authority (CTA), which operates the bus and rail systems serving Chicago and neighboring suburbs;
- Metra, which provides commuter rail service in six northeastern Illinois counties; and

- Pace, which provides bus service for the Chicago suburbs and supporting routes into Chicago. Additionally, Pace provides paratransit services in the region and is the regional administrator of the vanpool program.

Together, RTA and the service boards include:

- A service area spanning six counties including 9 million and 3,700 square miles
- 650 million annual riders and over 2 million daily rides
- 5,640 bus and rail cars
- 400 routes between 380 stations and totaling 7,200 route miles
- 650 vanpool vehicles
- More than $42 billion dollars in combined assets ($142 billion including the subway tunnels infrastructure)

Asset Management Approach

RTA is working to improve its asset management practices both to help allocate resources as efficiently as possible, and in response to legislative requirements. Illinois' RTA Act, as amended January 2008, requires the RTA to use performance measures to assess whether the transit system is meeting the needs of citizens and the region, and requires the RTA to develop criteria for evaluating capital projects. In response to these requirements in 2009-2010, RTA completed a Capital Asset Condition Assessment (Baseline Assessment), and is in the final phase of completing the first year update to the baseline condition assessment (the Update), and is now developing a Capital Decision Prioritization Support Tool (the Decision Tool).

The Baseline Assessment was performed to estimate RTA's capital needs over a 10-year period, including anticipated replacement, rehabilitation, and maintenance needs that would need to be addressed to bring all RTA assets to a state of good repair. To perform the assessment, RTA began by working with the service boards to define a consistent set of asset types and categories for which data were to be collected, established data types and naming conventions by asset type, and determined specific data items to be collected. The data collected included basic inventory information, in addition to asset age, useful life, past maintenance, lifecycle, and condition data. During the Baseline Assessment, it was determined to use age as the "predictor" of asset condition. The Baseline Assessment provided a limited verification of straight age-based ratings by conducting a limited sampling effort (1% of assets), which was used to compare actual asset condition against the age-based condition estimate.

With the Update, RTA decided to move beyond age only as the predictor of asset condition and to adopt several strategies to move towards physical asset condition assessment. The primary feature was the FTA-established asset condition decay curves. FTA has developed transit asset decay curves for every major asset type over multiple years, using a national basis for development (including, but not limited to, Chicago region assets). Additionally, the RTA will continue to utilize the TERM 1-5 condition scale for characterizing asset condition for all assets.

RTA projected that a total of $24.6 billion dollars would be required over a 10-year period to address the backlog and perform normal replacement and capital maintenance actions. Based on these calculations, RTA estimated that there was a $19.9 billion dollar discrepancy over a 10-year period between projected funding and the funding that would be required to bring all assets to a state of good repair.

Given the significant gap between state of good repair needs and available funds, an important aspect of RTA's asset management approach is the development of a decision support tool to help prioritize state of good repair projects based on available condition data and objective criteria. RTA's goal for the system is to prioritize the projects in its 10-year plan to help maximize results given available funding. RTA developed a pilot version of the the Decision Tool to use existing asset data and help support the existing capital plan development process adopted by RTA in 2008. Following development of the pilot, RTA secured FTA funds for use to enhance and document the capital asset condition assessment process and to develop an updated version of the tool. The TAM project will provide the service boards and the industry with improved asset management methods and advanced prioritization criteria practices. The TAM project will include condition assessment methodologies, data collection, asset assessment and analysis activities that will help the transit industry prioritize their asset maintenance, recapitalization, and replacement needs in order to obtain a state of good repair.

The first version of the Decision Tool was released in 2011 and the revised version is expected to be released in 2012. It uses a multi-criteria decision analysis (MCDA)-based approach to score candidate projects based on the following criteria:

- Asset age and condition
- Riders impacted, based on riders served by the asset location
- Service reliability, based on risk of service failures
- Safety and security, based on reduced risk of damage to passengers or assets
- Operating and maintenance costs

For each candidate project the tool calculates a weighted average total investment score, combining scores for each of the above categories. The tool is expected to yield a prioritized set of projects that is consistent with RTA objectives for its assets. RTA intends to use the tool to better allocate constrained funding for the achievement of state of good repair and will allow RTA to prioritize projects, analyzing each service board's projects separately. The tool will be available for both RTA and service board use.

Benefits/Outcomes

The asset management has yielded significant benefits for the RTA and its service boards:

- There is a consistent approach to defining and characterizing transit assets for RTA's three service boards. This effort has improved the quality of RTA's asset data, and provided more complete and consistent information regarding investments required to achieve a state of good repair.
- The Decision Tool, once fully implemented, is expected to help prioritize projects consistent with agency objectives, and maximize effectiveness of transit asset investments. It will integrate long-term asset needs with the region's project selection based five-year capital planning and annual budgeting processes.
- The enhancement of the asset inventory includes the development of an asset-to-project numbering convention within the context of RTA's Capital Decision Support Tool.

Sources and Other Resources

Information provided by senior contact at RTA.

Role of Operations and Maintenance Budgeting

Current Industry Practice

For many agencies, the link between maintenance budget and level of service is implicit but does not drive the budget process. Many agencies do evaluate the cost components of an operations and maintenance budget; however, these are rarely created with a "bottom up" approach. Agencies are often aware of their cost per revenue hour (or revenue mile) to provide service; however, the budget process is frequently siloed between capital and operations and maintenance investments, which can limit managing cost across the lifecycle.

The operations and maintenance budgeting process allocates operating funds to maintenance activities across all assets. Similar to the capital programming process, adopting an asset management perspective encourages performance-based decision making. This guide is focused on the maintenance portion of the operations and maintenance budget and promotes the following:

- **A maintenance budgeting model that explicitly links the maintenance budget to level of service or performance in a process that considers the relationships between maintenance activities and asset management objectives**. As a result of this approach, at the agency level and by asset class, an agency is able to describe what "level of maintenance service" is "bought." This is based upon the maintenance budget that is created to support specific asset management outcomes.
- **Maintenance requirements that are identified when an asset is procured or created**. This would specify the preventive and related maintenance activities required for the optimal lifecycle management of the asset. This encourages integration of procurement, maintenance facilities design and management, project management, parts management, maintenance, and capital functions because these are all related. Building on and addressing the link between design and operations, maintenance, and rehabilitation is a key component of transit asset management.

The Toronto Transit Commission (TTC), on behalf of Metrolinx, provides an example of an agency considering the lifecycle costs of a light rail line before it is constructed. The agency is working to design and engineer the Eglinton Scarborough Crosstown Rail Transit (the Crosstown) project. While still in the design phase, the TTC developed an operations and maintenance cost model to estimate the initial 30 year lifecycle costs (including operations, maintenance, and capital rehabilitation costs). The model uses level of service metrics, including revenue vehicle kilometers, revenue vehicle miles, and number of vehicles to drive the lifecycle cost estimate. This modeling exercise is allowing Metrolinx and TTC to better understand the financial commitments that will be required to keep the Crosstown in a state of good repair to support safe, reliable transit operations. Additionally, the early implementation of operations and maintenance planning can identify opportunities that will inform the system designers to make appropriate design adjustments, which could reduce the overall lifecycle costs as the Crosstown system matures.

An asset's lifecycle management plan outlines the estimated maintenance costs associated with maintaining a specified level of service for that asset. This level of service supports the agency's target level of service. As Figure 3-13 shows, best practice suggests that operations and maintenance budgets be developed from the "bottom-up" based on input from the lifecycle management plans (with consideration for other operations and maintenance budget cost drivers, including labor agreements and service contracts).

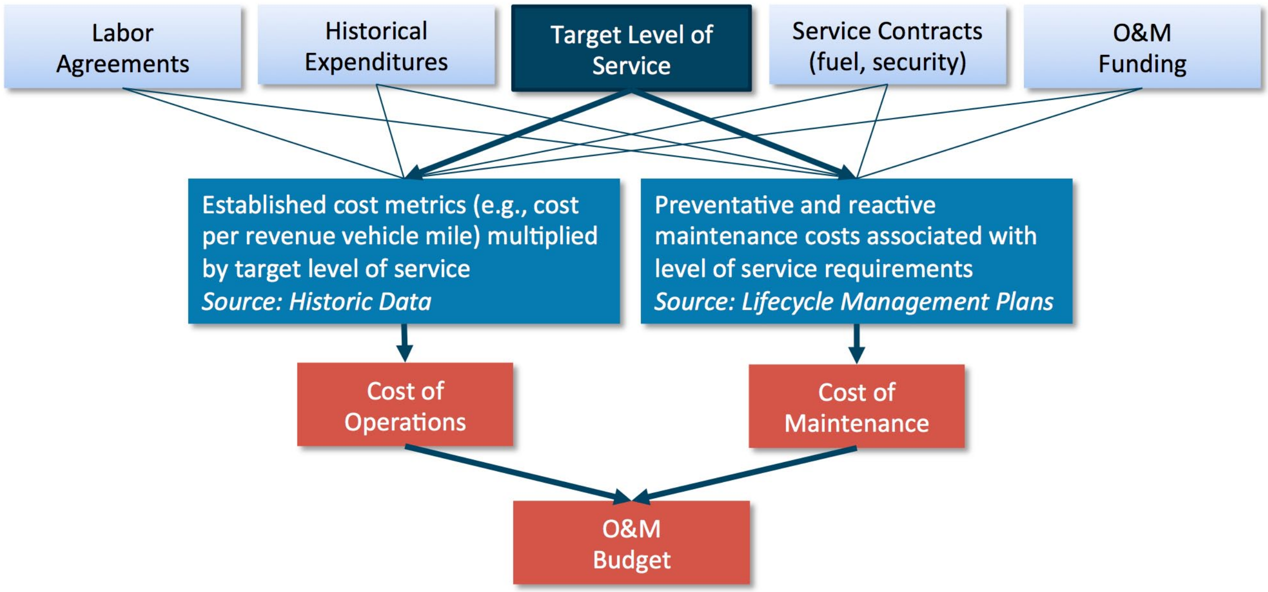


Figure 3-13 *Establishing the Link between Level of Service and the Operations and Maintenance Budget*

In many cases, an agency's operations department has a much stronger influence on the operations and maintenance budgeting process than maintenance. In many cases, an agency chooses to maintain its existing level of service but defer maintenance to compensate for funding shortfalls. This can have significant long-term performance implications. The types of linkages between maintenance budgets and level of service advocated in this guide can be used to support performance modeling and to facilitate stakeholder communications regarding the short- and long-term impacts of under-funding maintenance.

Some of the benefits associated with having an improved operations and maintenance budgeting process include the following:

- Improves the transparency and understanding of the overall maintenance budgeting process.
- Provides clear link between agency goals (target level of service) and operations and maintenance budget decisions.
- By maximizing the balance between routine and preventive maintenance activities and capital investments, agencies can maximize performance and minimize costs and risks over time.
- Provides internal and external stakeholders with clear justification for funding trade-off decisions.

Operations and maintenance budgeting success factors:

- Performance based cost data from the lifecycle management plans used to develop an operations and maintenance budget from the bottom up
- Performance based culture and approaches to maintenance budgeting
- Complete, up to date, and accurate lifecycle cost, risk, and performance data combined with a clear understanding of the agency's level of service goals
- Trade offs associated with investment choices identified by involving members of the capital programming team in the operations and maintenance budgeting process

Key implementation principles associated with the establishment of an effective operations and maintenance budgeting process include the following:

- Similar to a construction review, the agency can require a maintainability review during the design and procurement process to ensure that assets being procured or constructed can be maintained in a cost-effective manner that supports the agency's goals. This includes addressing procurement contracts, warranty management, and other factors that affect managing across the lifecycle.
- The maintenance budget reflects input from the executive team (regarding the targeted level of service) and asset owners (regarding their respective asset's maintenance costs).
- If scenario evaluation is available, the operations and maintenance budgeting process incorporates the findings associated the relevant analysis and discussions.
- When possible, asset owners communicate the potential negative consequences associated with deferred maintenance. The more clearly an investment can be tied to an agency goal or performance objective, the more compelling a case will be.
- In many cases, the capital program and operations and maintenance budget are developed independently. When possible, agencies develop these budgets on the same schedules and consider implications to the operations and maintenance budget when the capital program funding is increased or decreased.

Case Study

Victoria Department of Transport: O&M Budgeting

Relevance of Case Study

This case study demonstrates how an outsourced, highly mature asset management program considers the total cost of ownership of its assets by agreeing on cost and performance requirements during its competitive bidding process.

Agency Overview

The Victoria Department of Transport (DOT) is responsible for the public transport system in Victoria, Australia, including rail, trams (streetcars), and buses. Annual ridership in Melbourne is approximately 262 million passenger trips. The system includes the following services:

- The rail system in Victoria comprises 17 routes operated on more than 5,000 miles of track. Trains serve passenger routes, as well as intrastate and interstate routes throughout Victoria, carrying a mix of passenger and freight traffic.
- The tram system in Melbourne consists of 26 routes with more than 150 miles of track. Tram service is provided using approximately 530 trams and 1,740 tram stops.
- Passenger rail service in Melbourne is provided using approximately 900 rail cars (operating in 6-car trains) and 209 stations.

Victoria's public transport system was privatized in 1999. Following initial financial issues and a restructuring in 2004, the Victorian Rail Track Corporation (VicTrack) now owns the railway land and infrastructure and leases it to Victoria DOT. Victoria DOT, in turn, contracts with a number of franchises to provide transportation services.

Asset Management Approach

Victoria DOT has a comprehensive asset management approach that is documented through government policy and franchise agreements. The organization has a policy of no single-order failures affecting operations—failures in the system should never be evident to users. This requires a focus on condition-based interventions to fix potential issues before they arise.

Victoria DOT requires an asset management plan from each franchise holder. The plan describes the franchisee's approach to asset lifecycle management, including inspection, maintenance, and quality assurance, as well as performance standards and response times. In addition, each franchisee submits an Annual Works Plan specifying planned capital projects. Franchisees report quarterly on a set of key performance indicators for infrastructure and rolling stock, including condition indices and other measures.

The operations and maintenance budgets are developed by the franchisees as part of the competitive bidding process and are agreed to at the start of the franchise. The only reason these can change is if the state introduces a major capital project (such as a line extension) that fundamentally changes the operating costs of the railway. Ultimately, the franchisee has a day-to-day performance obligation for a safe and reliable railway. They also have a longer-term obligation to achieve a minimum scope of renewal and replacement work that is agreed at the start of the franchise and must be delivered unless agreed otherwise.

Capital purchases are chosen carefully based on lifecycle costs and performance of assets. An effort is made to map all costs of an asset—most importantly, the costs of risk-to-service as maintenance needs arise years after purchase. In one recent instance, Victoria DOT chose a monitoring company that offered to install equipment for free, and that company guaranteed that the maintenance and usage fees over the life of the equipment would amount to less than the overall savings.

An important component of Victoria DOT's lifecycle management approach is to maintain an asset inventory that details the inventory and condition of the rail infrastructure, compiled in the Privatized Assets Support Systems Assets Database. The management of existing assets is driven by the lifetime output required of the assets. Franchisees' payments can be withheld if this inventory is not updated.

Benefits/Outcomes

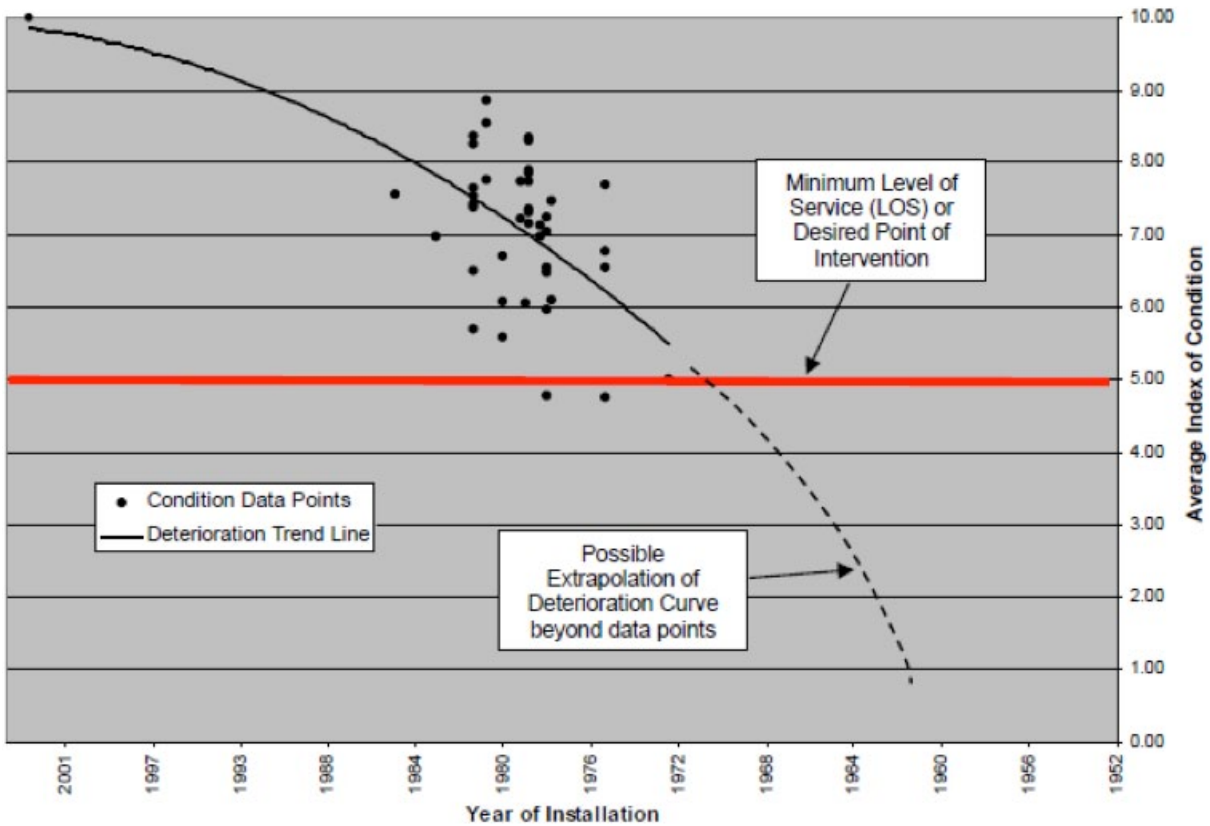
- Operations and maintenance budget that guarantees maximized asset performance for the term of the franchise agreement
- Established performance measures that can ensure Victoria DOT's goals are being managed and met
- More cost-conscious organization
- Comprehensive, integrated web-based inventory of rail infrastructure

Sources and Other Resources

Information provided by a senior contact at Victoria DOT.

Role of Performance Modeling

In this guide, performance modeling refers to the practice of monitoring and predicting asset condition based upon different funding decisions. It is a data-driven process that applies analytical tools and procedures designed to forecast the performance impacts of different budgeting decisions, finance plans, and lifecycle management plans. This can occur with varying degrees of sophistication. Many agencies use basic spreadsheets to model the condition or performance of one asset class over a period of time (see Figure 3-14). On the other hand, only a small minority of agencies are conducting scenario evaluation of their agency-wide assets (see MTC example on following page).



Source: Rushbrook and Wilson, 2007

Figure 3-14 *Sample Asset Class-Specific Example – New Zealand Railways Hardwood Rail Tie Condition Index by Age with Fitted Decay Curve*

These modeling approaches all, to some degree, are informing the stakeholder communication, budgeting, or lifecycle management processes:

- **Stakeholder Communication** – Performance modeling enables the impacts of various levels of funding on asset condition (state of good repair) and performance to be considered. Current use of such information tends to focus on communicating condition and "needs" across assets in a consistent way. It increases the understanding of the performance and fiscal consequences of not meeting optimal lifecycle management requirements for capital and/or maintenance work. Similarly, the information can be used to communicate the fiscal and performance benefits from increased state-of-good repair funding.

As asset management practices mature, the link to performance (for example, system reliability) is increasingly made and communicated. In this way, performance modeling provides data-driven information to communicate the impact on reliability, asset condition, asset value and other outcomes of asset investments.

- **Budgeting** – Performance modeling for budgeting involves using data-driven analysis to link resources applied to level of service. Information from performance models can be integrated directly into the capital and operations and maintenance budgeting process as discussed the section titled "Role of Operations and Maintenance Budgeting." Since this process requires a mature asset management organization and analytical capabilities, most transit agencies in the U.S. are not using these types of processes to build their budgets; however, it is a key component of performance-based management. (See Massachusetts Bay Transportation Authority [MBTA] case study at the end of this section.)
- **Lifecycle Management** – Performance modeling enables asset owners to evaluate the effectiveness of specific strategies to evaluate performance implications. For example, an agency can monitor how different cleaning techniques or rehabilitation timing might affect performance by modeling that asset's performance over a specified period of time.

The Metropolitan Transportation Commission (MTC) is the Metropolitan Planning Organization (MPO) responsible for the nine county San Francisco Bay Area. The MTC is not a transit operator, but is the agency responsible for transportation planning and financing for 25 transit agencies in the Bay Area, including the San Francisco Municipal Transportation Agency (SFMTA), Bay Area Rapid Transit (BART), AC Transit, and Santa Clara Valley Transportation Authority (VTA). These agencies provide commuter rail, heavy rail, light rail, bus transit, trolley bus, cable car, and ferry service to the Bay Area. Together the Bay Area transit systems carry more than 1.6 million passengers per day, operating more than 4,400 vehicles on approximately 580 routes.

Data on Bay Area transit assets is important for long term planning and supporting project prioritization decisions. The MTC's major source of asset data is the Regional Transit Capital Inventory (RTCI). The RTCI was developed in 2007 to support analysis of long term investment needs based on the inventory of transit assets rather than a defined set of projects. The MTC populates the RTCI with data provided by each transit agency. For the first phase of RTCI development, the MTC obtained data on approximately 80,000 assets, including vehicles, guideway, track, roadway, stations, facilities, and systems. For each asset, the RTCI predicts needs for asset rehabilitation and replacement based on the existing age of the asset and predicted service life. The system predicts unconstrained needs over time, as well as the dollar value of the backlog of deferred replacement and the Percent of Assets Over Useful Life (PAOUL). MTC's goal for Bay Area transit assets is to achieve a PAOUL of 50%, which is the value obtained if assets are uniformly distributed in age and replaced at the end of their useful life. The RTCI is used to analyze long term investment needs, but is not a project prioritization tool.

Performance models are used to communicate to customers, policy-makers, and stakeholders the relationship between state-of-good-repair investments and asset condition and performance. Performance modeling enables data-driven approaches to optimizing the nature and timing of preventive maintenance and rehabilitation. Performance modeling at the agency level involves the following steps:

1. **Measure and communicate the current asset condition baseline**. The first step involves establishing a baseline analysis of current conditions and level of service. This is data-dependent and, ideally, uses information provided from the lifecycle management plans, such as asset age, condition, and performance. It also relies on asset decay curves, which can be used to predict an asset's condition over time. Asset decay curves can be based on industry data[15] or, ideally, an agency's actual data. Establishing the baseline also relies upon one or more consistent condition and/or performance metrics to communicate the baseline. So, for example, the baseline may be communicated with a state-of-good repair measure (for example, the percentage of assets with a condition measurement of 3 or better out of 5) or a performance measurement (for example, on-time performance or mean distance until failure).
2. **Confirm Direction and Level of Service Target** – The agency-wide asset management policy, strategy and plan provide the starting point for specifying the objectives for asset level of service and condition. These objectives provide direction for evaluating the baseline against a desired state. For example, the agency's asset management policy may require 98 percent on-time performance.
3. **Evaluate Alternative Policy and Investment Scenarios** – Scenario analysis involves assessing the impacts, influences, or effects that various scenarios have on the asset management objectives. The scenarios provide a common framework for all parties to discuss the impact of alternative investment decisions while taking future uncertainties into consideration. Ideally, this information is incorporated into the capital programming and operations and maintenance budgeting processes.

Performance modeling success factors:

- Agency is committed toward establishing robust performance management processes
- Defined level of service goals for the agency and assets
- Completed lifecycle management plans that clearly outline the link between condition and performance
- Agency wide, consistent condition assessment monitoring and reporting

[15] Industry data for asset decay curves are available through the FTA's TERM model.

Through the use of financial analysis, predictive modeling, and forecasting tools, scenario evaluation can improve decision making and communications by predicting asset condition and performance based on varying funding levels, capital and maintenance budgeting, and policy changes. This provides a valuable mechanism for communicating with and providing accountability to policy-makers and the public.

Some of the benefits associated with a performance modeling process include the following:

- Enables policy-makers to understand the implications of different resource allocation decisions and support prioritization across goals.
- Optimizes decision making through the use of comprehensive and reliable forecasts.
- Improves stakeholder understanding of link between state-of-good repair investments (or dis-investments) and performance.

"Our deterioration curves will probably be based on industry data at first, but, as time goes on, the goal is that our agency will be able to define our own deterioration curves for different asset classes."

–Transit Agency Manager
(Source: 2011 Parsons Brinckerhoff Survey)

Key implementation principles associated with the establishment of a performance modeling process include the following:

- An agency communicates how performance modeling is intended to be used (that is, planning versus budgeting) so that there are clear expectations.
- Performance modeling relies on significant amounts of data, including, for example, age, condition, useful life, operating statistics, and historic condition data (decay curves).
- Lifecycle management plans for individual asset classes are developed consistently so that uniform asset data can be incorporated into the performance modeling analysis.
- The agency has a method for performance modeling using data from multiple sources.

Case Study

Massachusetts Bay Transportation Authority: Scenario Evaluation

Relevance of Case Study

This case study demonstrates how an agency uses asset age and lifecycle data and a scenario evaluation tool to forecast its state of good repair needs and support capital programming.

Agency Overview

The Massachusetts Bay Transportation Authority (MBTA) provides commuter rail, heavy rail, light rail, bus transit, trackless trolley, bus rapid transit, and ferry service to approximately 1.3 million passengers per day in the Boston area. The MBTA has an extensive inventory of vehicles and fixed assets, including the following:

- 2,500+ bus and rail vehicles
- 275 stations
- 885 miles of track
- 20 miles of tunnel
- 476 bridges
- 19 maintenance shops

The MBTA's system has been in operation for more than a century. The subway opened in 1897 and is the country's oldest. The system went through a period of rapid expansion in the 1970s, '80s, and '90s, with extensive new commuter rail and rail transit service added to the system.

In 2000, the MBTA moved to a different funding approach that provided a dedicated funding stream but required the agency to operate within a budget. The shift in the MBTA's funding approach forced the agency to assess the condition of its existing assets and determine its needs over time for keeping the expanded system in a state of good repair. Achieving a state of good repair is recognized as a major challenge for the system.

Asset Management Approach

The MBTA's efforts to implement an asset management approach began in 1999 in conjunction with the shift to forward funding. At this time, MBTA initiated a state of good repair capital programming effort, recognizing the need to better characterize the condition of existing assets and shift from expanding the system to maintaining it in an state of good repair. As part of this effort, the agency improved its asset inventory, assessed the conditions of its assets, and defined, for the first time, what constitutes a state of good repair. The MBTA currently defines state of good repair as the "condition where all assets perform their assigned functions without limitation." For the purposes of modeling state of good repair, this translates to an asset age being less than or equal to its useful life.

Since 2006, the MBTA has used its state of good repair database for validating whether its capital programming is in line with its state of good repair investment needs. The state of good repair database is a comprehensive database and analysis model that includes the following:

- Information on more than 2,900 assets
- Ability to synthesize capital needs information received manually from managers throughout the organization
- Ability to objectively generate reports that depict "what if" scenarios

The state of good repair database analyzes individual capital asset records using cost, age (and condition, indirectly), useful life, renewal activity and other user input. Based on user-specified weights, the system simulates allocation of a specified budget to investment needs over time. The system creates and reports on scenarios involving 5-year capital improvement programs and 20-year strategic capital investment plans, predicting the number of assets that are within their useful life, and distribution of funds given a budget.

In the near future, the MBTA staff will be evaluating the potential for incorporating the following into their state of good repair system:

- Condition data (as opposed to just age-based decision making
- Decay curves
- Web-based capital needs form
- Integration with capital programming decision-making software
- Improved data management practices

Benefits/Outcomes

- The MBTA has used state of good repair data to report to the Massachusetts legislature on its funding needs to address the state of good repair backlog. As a result of its emphasis on state of good repair concerns, the MBTA has shifted its capital spending to focus almost exclusively on achieving state of good repair (as opposed to expansion projects). In the 1990s, only 60 to 70 percent of the capital budget was allocated for projects related to state of good repair. In the 2012—2016 capital plan, more than 95 percent of MBTA capital funds were allocated to projects related to achieving state of good repair.

- The MBTA now has the ability to prioritize projects based on a transparent process using objective data. The reports generated from the state of good repair system helps inform the capital programming process.
- The state of good repair system has also helped the MBTA communicate its asset conditions and investment needs to other stakeholders, including the Massachusetts legislature, metropolitan planning organizations, and the public. Furthermore, through better communication about the conditions of its assets through the state of good repair database and Scorecard, the MBTA hopes to strengthen accountability and public support for the system in the future.

Sources and Other Resources

Information provided by senior contacts at MBTA.

SECTION
4

Asset Management Information Systems

At its core, asset management applies rigorous, fact-based decision making, using information about the performance of an asset across its lifecycle. Integrated asset information that can be analyzed and readily reported is fundamental for effective performance assessment and asset management.

Contemporary best practice—either at the enterprise level or during any aspect of lifecycle management for individual asset classes—depends upon the application of information technologies. Converging information and operations technologies enable real-time monitoring of condition and performance, providing new opportunities to employ technology to improve asset management outcomes. This section presents the following sections to help agencies make informed system decisions:

- Transit agencies and asset management information systems
- Components of an asset management information system
- Implementation principles
- Vision of a high-functioning transit agency asset management information system

While this section demonstrates the scope and complexities involved in integrating information systems to support asset management in larger agencies, smaller agencies—many with bus-only systems—can apply the same principles using well-developed components (such as fleet management systems) that incorporate the principles of the asset management information system demonstrated in this section.

Section 5 provides detailed guidance on implementation steps.

As explained in the asset management framework introduced in Section 2 (Figure 2-7), information systems as well as management practices are the foundation of any asset management initiative, where the systems support the asset management process and practices. Whether an agency is developing its asset inventory or using decay curves[16] for performance modeling, the asset data needs to be stored, managed, and analyzed in one or more information systems for effective management. Information systems can support all of the asset management business processes. Figure 4-1 functionally depicts an integrated asset management system. The arrows on the left depict key actions that support asset management functions (shown in the triangle). The boxes on the right of the figure present key functionalities provided by the asset management system.

Asset management information systems provide data in a timely and easy to understand manner for management decisions and in support of engineering, capital programming, and risk management decisions. Integrated data and access to historical data enables an agency to manage across functions and over the lifecycle of long lasting assets, resulting in better informed decision making and decision support processes.

Transit Agencies and Asset Management Information Systems

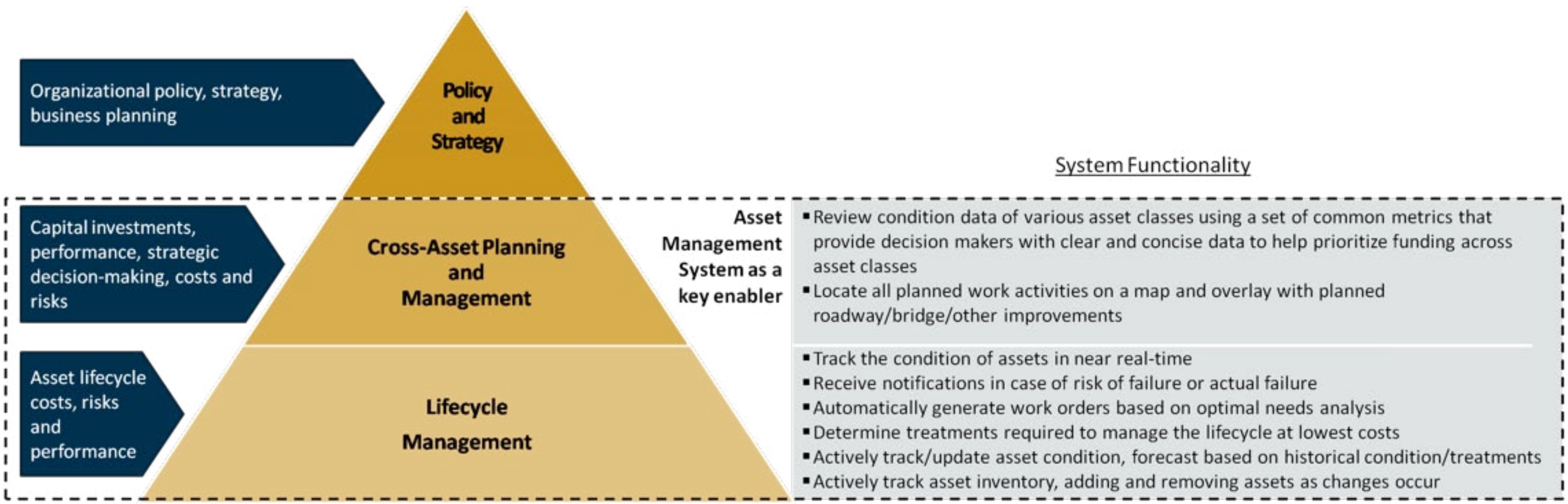
All transit agencies have information systems of one type or another (with differing levels of automation) to support asset management and related activities. Improving them offers both opportunity and a significant management challenge.

Many agencies are confronted with a legacy environment of data management practices, information systems, and processes, which (while they support business as conducted today) do not provide the information required for

[16] Decay curves or deterioration curves refer to a graph that shows the condition of an asset against its age. Such curves help to effectively predict the future condition of an asset. Different assets have different deterioration curves based on location, weather, usage pattern and other factors.

mature asset management. This situation is frequently compounded in agency business environments where information technology investments have not been agency priorities. This presents many challenges related to asset management information systems.

While many Commercial Off The Shelf (COTS) asset management-related software exist, each software product has its own strengths and weaknesses. No single commercially available system appears to address all aspects of the asset management framework outlined in this document. Transit agencies with multiple modes and a diverse asset portfolio are likely to require combinations of systems, or, at a minimum, substantial product customization to meet the types of needs addressed in this transit asset management framework.



Source: Adapted from the Institute of Asset Management's *An Anatomy of Asset Management*.

Figure 4-1 *Functional Depiction of an Asset Management System*

Asset Management Information System Components

The fundamental asset management activities and how they are enabled by the various components of an enterprise asset management system are shown in Figure 4-2. For each basic management action (shown in blue), a corresponding function or component of an enterprise asset management system is shown in green. A description of each component follows the figure. When referencing the figure and considering the following sections, it is important to note that there are different technical systems solutions for providing the components of an asset management information system (the green elements of the diagram).

Asset Inventory

The asset inventory component of the asset management system identifies all critical assets, their location, and important attributes such as age, expected useful life, cost, and type of asset. As discussed in Section 3, this guidance suggests that the asset hierarchy should go down to the "maintainable unit" to meet business process needs. The asset inventory system/tool should either provide the capability to record asset condition data, including history, or allow for a mechanism to seamlessly link to this data. Also, the system should allow for the data to be not only stored but also easily recalled for reporting and analysis. Having a comprehensive inventory depends not just on the tool but on the quality of data in the system—it is important for an agency to have an up-to-date inventory, correct categories, and hierarchy (data relationships between key elements). (For more information on asset inventorying, see Section 3.)

Asset Management Information System Challenges

Many agencies have developed tools internally within divisions based on their specific needs. These tools may, individually, provide the required functionality; however, they generally do not integrate or exchange data with other systems, severely limiting their ability to support enterprise or department-wide decision making. Also, many times, the systems that met an agency's needs on a small scale cannot support the agency's needs as the departments grow. Many agencies have a well defined strategic IT direction to replace their aging system architectures, but implementation has been slow.

Asset Condition

The condition data component provides a location to store raw condition data, aggregate condition data (converted to level-of-service measures/metrics), and ratings for the assets based on thresholds in the system. This dataset largely makes up the fundamental performance characteristics of assets within the system or agency.

Some of these asset condition tracking systems can also track deterioration/decay curves based on not only agency data but data available from other transit agencies. Tracking decay curves allow agencies to forecast the conditions of various assets at a granular level based on current asset condition and age, thus helping to make and justify programming decisions. Asset inventory and condition data is generally stored in the same system to allow for clear "connections" between the two. (For more information on asset inventorying, see Section 3.)

Figure 4-2

Asset Management System Components and Functionality

Active Condition Monitoring, Detection, and Tracking

Active tracking systems track and provide asset condition data in real-time/near real-time. Such tracking provides significant benefits for managing various assets, especially fixed assets. Such systems include rail track monitoring systems that track rail stress and earth movement; bus monitoring systems that monitor condition of vehicle components such as brakes, electrical, oil pressure; and subway monitoring systems that track the state of subway doors (closed, ajar, etc.). Such systems allow an agency to record up-to-date condition information (in asset condition components listed above), and when linked to inventory and historical condition, conduct preventive maintenance activities when required, which have the potential to reduce lifecycle costs. This link between traditional business intelligence (data mining and assessment) and asset management is a key value to many agencies that remains largely untapped within the industry.

Maintenance Management and Asset Management

The terms "maintenance management" and "asset management" are frequently used interchangeably in the industry; in fact, they are quite different. While the primary purpose of maintenance management is to manage maintenance activities (which activities are performed on which asset, cost of maintenance, etc.), the primary purpose of an asset management system is to provide a whole life view of all assets, allow monitoring, tracking, and analysis of how funding strategies affect asset condition, and allow the agency to make policy and strategic decisions regarding funding (cross-asset decision making, investment decisions). Maintenance management focuses more on the short term activities, while asset management is intended as a proactive approach to managing enterprise investments over the longer term. Maintenance management should be envisioned as a subset of asset management. The term "enterprise asset management" refers to asset management conducted at an enterprise level instead of just one section/ department of the agency/ enterprise.

The maintenance management system, when integrated with business intelligence, condition tracking and forecasting, and other enterprise tools, forms a true enterprise asset management system/tool.

The largest benefits from such systems are derived when the data is seamlessly tied to historical asset condition and past work activities. These benefits also allow an agency to conduct root cause analysis of the failures, and, in some cases, review the trends to identify and forecast problems to monitor. This information significantly increases an agency's capability to conduct targeted, effective maintenance activities. Technological improvements have allowed agencies to acquire new assets with condition tracking systems, but older assets (for example, older buses) may not have the same onboard technology.

Details about condition monitoring systems specific to each of the transit asset classes are provided in the *Asset Management Guide Supplement*.

Maintenance Management

A maintenance management system/component helps schedule and track the work orders for assets, when the work is conducted, associated labor and equipment costs, materials management, and in some cases, the condition of assets forms an important component of the asset management system. Various agencies use COTS packages for maintenance management, while some agencies use tools that were developed in-house. Maintenance management systems designed specifically for transit agencies generally include fleet management, fuel management, and other components listed separately here.

Fleet Management

Agencies are also increasingly adding fleet management systems to track warranties, claims, and any vehicle accidents/other incidents. Such data can significantly reduce an agency's cost by claiming in-warranty repairs from the manufacturer and analyzing any trends in vehicle accidents. Many fleet management systems also include parts inventory management capabilities. Some maintenance management systems designed for transit agencies provide fleet management capabilities.

Parts Management/Inventory Control

A parts management system/component allows the agencies to track the number of parts available for mission-critical assets, and allows the agency to maintain an optimal number of parts. This ensures that the critical assets do not suffer from downtime because of lack of parts, while the agency does not have too much cash tied in stored parts. It enables better service and better performance and allows for modern supply-chain management practices.

Facilities Management

Fixed assets, like buildings and equipment, are significant components of an agency's asset portfolio. Stations, stops, transit centers, and train and bus maintenance facilities are critical to meeting customers' needs. Tracking and maintaining these facilities is important for agencies, and a facilities management component provides the correct tool for such management. Facilities management is often a component of maintenance management or enterprise resource planning (ERP) systems.

Scenario Analysis and Decision Making

After the data from the various components of an asset management information system are integrated (and with the right analysis and reporting capabilities), this data can be used to communicate in a consistent way the state-of-good-repair needs of the agency across all asset classes. It allows the agency to review and describe scenarios for the future state of good repair under different capital programming and funding scenarios. This type of capability allows for a transparent consideration of trade-offs and their implications in the planning and budgeting process. This provides decision-support information that allows the agency to select and prioritize among assets and projects, including expansion and state-of-good-repair projects.

Further analysis of completed projects allows the agency to improve its prioritization process and update its asset condition forecasts. An agency's decision-support system can provide comprehensive analysis of all enterprise data, and provides a capable scenario analysis tool. This tool can provide flexible reports and data to understand the impact of various funding (and other) decisions, and support such decisions with data.

Financial, Accounting Management, Engineering, and Other Systems

Financial, accounting management, human-resource (HR) management and other similar systems provide agencies with the capability to use a central system for tracking various costs, benefits, invoicing, and other financial, accounting and HR functions. These systems have a wealth of data surrounding labor, material, and equipment costs. In addition, such data allows for improved financial planning—leading to significant organizational benefits. Linking cost data to the asset across its lifecycle requires integration between these systems, adding a further technical challenge in today's transit agency technology environment.

Such data, as well as maintenance management and project management systems, allows stakeholders to obtain a complete picture of the total costs of a maintenance activity (including labor and materials), activities performed on an asset, and any budget/schedule overruns. Agencies generally use an ERP system that integrates the aforementioned financial, accounting, and HR data.

The use of engineering systems, such as GIS and spatial data tools allows the agency to understand the physical location of its assets. Integrating asset inventory and fleet management data with GPS (location) and GIS data aids in real-time transit reporting (for tracking and reporting, say, bus location and estimated time of arrival to the public).

Technical Solutions to Integrating Asset Management System Components

The asset management system components, when tightly integrated, form an agency's enterprise asset management (EAM) system. How this is accomplished varies between agencies, and the technical architecture for an information systems solution that supports asset management will be determined by a series of context specific decisions. For transit agencies, these will be driven by the portfolio of assets and the legacy environment of processes, practices, and information systems.

The intent of this guide is to address functionality—the attributes of mature transit asset management practice—and provide information to agencies with asset management improvement programs. Therefore, while this guide does not provide systems solutions, it does provide a conceptual architecture for integrating the basic components of asset management information systems. Figure 4-3 presents the components and links for an ideal asset management system in the form of a conceptual architecture.

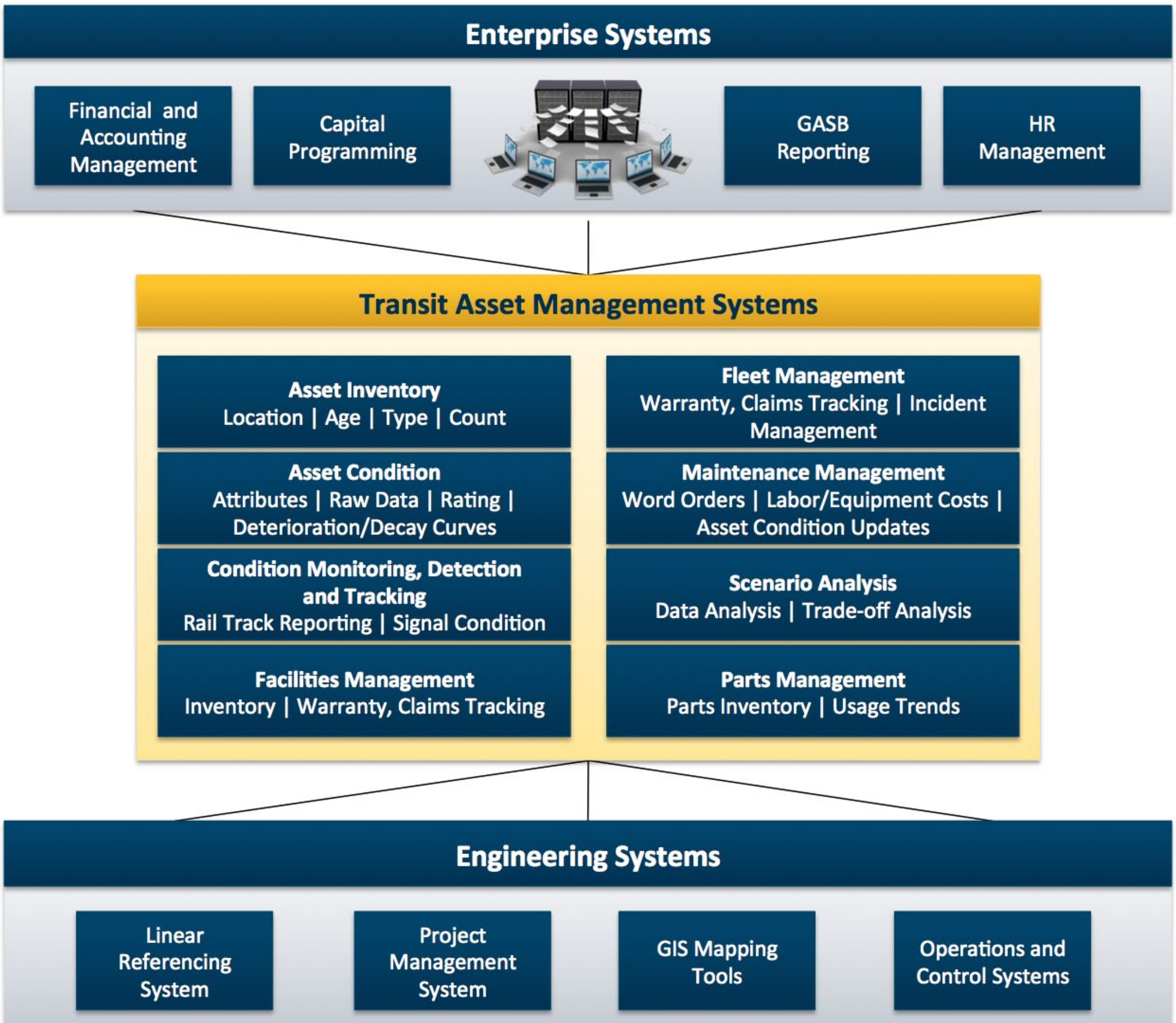


Figure 4-3 *Illustrative Conceptual Enterprise Asset Management Architecture*

The functionality of many of the components listed separately here can be met by one system. That said, the goal of an agency need not be to have just one system for all the functions, but a series of well-integrated systems that allow all stakeholders to perform the required functions. The number of integrated systems largely depends on an agency's current and/or planned architecture, systems in place, any state or local mandates, and any planned upgrades.

Implementation Principles

The following key principles are associated with successfully implementing an EAM system (refer to Section 5 for more implementation guidance):

- **Recognize that tools support the process** – The asset information system supports and enhances asset management practices, but is not a substitute for those practices.
- **Provide executive sponsorship and leadership** – Executive sponsorship and leadership are crucial in influencing the project's process, progress, and the final outcome. Executive sponsorship will ensure that project team members and subject matter experts fully support the project efforts and are accepting of changes that may result from this project.
- **Define and follow clear system requirements** – Firm and consistent basic requirements provide clear and obtainable goals that will reduce the effect of change. User input will play an important role in establishing firm, basic requirements.
- **Involve users** – User involvement early on and throughout the project helps ensure that the system meets real needs and will be used. Users should include organizational leaders, asset owners, and maintenance staff. These users generally have different individual needs within the corporate goals as well as varying levels of software experience.
- **Ensure effective data governance** – It is important to ensure that data terminology is clearly defined, and that data collection and storage practices are standardized and well understood throughout various divisions. (Key implementation principles associated with managing the data are presented in Section 3.)
- **Commitment to data updates** – Information systems are only as good as the data they contain. As time passes, updating inventory and condition data is critical and agencies need to explicitly commit to keeping data up to date in the system to keep it useful.
- **Build upon existing system infrastructure** – An agency should evaluate the age, functionality, and flexibility of existing system infrastructure and attempt to use existing systems to the extent possible. A review of how the EAM architecture could be built using some of the existing components, along with new components that are necessary, is important to ensure maximum benefits for incurred costs. This does not mean that the

architecture should include all, or even most, existing systems, but that the existing systems should be properly reviewed for their current and future abilities.

> The most useful information systems are those that are business driven, supporting the agency's day to day and longer term needs.

Vision of a High-Functioning Transit Agency – Asset Management Information System

Similar to the Visioning Section (Section 2), this section is intended to describe how improved asset management information systems can impact many functions in a transit agency.

General Manager

"On a regular basis, I get asked by stakeholders, 'What is your on-time performance and how has it changed over time?' or 'If we find you additional funding, how would you spend it?' In the past, I was never able to answer these questions on my own. In fact, these questions required significant data compilation and analysis. I would ask my management team for assistance and they would ask their teams to spend hours, if not days, pulling together cost, project, and performance data. I know it was disruptive, but what else could I do? Sadly, our board members and customers were not impressed by our slow response, and they often found that we were sharing out-of-date and inconsistent information. Now that we have integrated systems with comprehensive data that is updated on a regular basis, I've got data at my fingertips to provide immediate, accurate responses. This has improved our ability to communicate our successes, justify our needs, and save both time and money."

Capital Programming & Finance Manager

"My job is to facilitate the process of prioritizing how we spend our capital and O&M [operations and maintenance] dollars. Most of our budgeting decisions were based on using the past year's cost estimates combined with input (mostly anecdotal) from managers. Many of our managers have been doing this for decades, so they have a good sense of system needs and project costs, but I knew most of them are going to be retiring soon. Now that we have a comprehensive asset inventory with detailed information about the asset's criticality and condition, we are making better informed decisions than ever. Not only that, but we are using a decision making tool that utilizes the asset inventory data and incorporates the prioritization criteria that best supports our agency's goals. Some of our managers argue with the outcomes, but we've now got reliable policies and data to defend our decisions."

Railcar Maintenance Manager

"We have always had a maintenance management system that specified what work needed to be completed when, so I was quite skeptical about any system changes. Our team, basically, fixed things when they broke and the system seemed to run just fine. Now, I understand how different things can be. We still have to fix things when they break, but the majority of our work is focused on preventive maintenance. We use handheld computers to track the condition of the railcars and we can easily look up the maintenance history for the railcar as a whole or any of its components. Just recently, the system alerted me that we kept having to replace the same part in all railcars from a certain manufacturer, so now we're proactively replacing that component in every railcar in that series. This is different than the manufacturer's recommendations, but it makes sense because of our region's climate. I've been excited to see how this approach has had a direct impact on our on-time performance and mean distance between failure performance metrics. And, we are able to use our cost savings to fund additional maintenance staff, I don't know why we didn't see the net benefits before this and improve the system earlier."

SECTION

5

This section provides guidance on planning for and implementing the process and practices described in the rest of this guide. This section also introduces key implementation concepts, provides an agency self-assessment for determining the agency's maturity level, and outlines potential implementation paths for incorporating into the agency's asset management plan. Finally, it outlines implementation considerations and lessons learned.

Implementation Guidance

The fundamental concepts of asset management are straightforward; however, implementing the changes required to become a mature asset management organization requires careful planning and execution. An agency's current portfolio of assets and management practices is the result of decades of decision-making in environments with many institutional factors that limit the ability to integrate decision-making across asset classes and lifecycles. An agency that is organized to integrate decision-making across the entire asset lifecycle will be better positioned to apply the asset management processes and practices described in Sections 1 through 4.

Institutionalizing asset management requires a true shift in an agency's management and culture—toward outcomes that focus on reliability, total cost of ownership, and performance or level of service. A central theme for this implementation section is that attention to change management and building an asset management culture in the agency are critical. Becoming a highly performing asset management organization takes time and requires considerable change, but en route, significant near- and long-term performance improvements can be realized.

Summary of Implementation Principles

- **Understand your agency's asset management drivers** – Agencies undertake an asset management improvement program for various reasons (for example, a response to a mandate, a need for improved transparency, and a drive to improve performance and more business like management, among others). Your agency should develop an implementation approach that maintains that focus; however, the approach should be flexible enough that it can shift as priorities change.
- **Build upon existing strengths and practices** – Your agency should leverage its departments' existing asset management activities, identifying best practices and lessons learned with one asset class and applying these practices and lessons to others.
- **Provide value immediately** Through incremental implementation activities, your agency can quickly achieve results that demonstrate the value of implementing improvements to asset management practice and provide momentum for future activities.
- **Recognize that asset management is a process** – This guide identifies the core processes that provide a starting point for developing an asset management process that will pay dividends in improved service delivery and asset sustainability; however, your agency should recognize the importance of continually using your organization's experiences and those of its peers to improve asset management processes.
- **Prioritize people, tools, and information** – Asset management is, at its core, about data driven management, so your managers should identify the people who can understand and lead this change initiative and establish the data and develop tools that best support your agency's decision making processes.
- **Invest smartly** – Your managers should identify the investments that will provide the best "bang for the buck" and only if these investments support your agency's strategy.
- **Develop your human resources** – Your managers should identify the appropriate skillsets needed to implement the asset management strategy and invest in those people with recognition, incentives, and training.
- **Provide top-down leadership and assign clear ownership for asset management activities** – Strong leadership will set expectations and accountability for implementation, while your asset owners should "own" and drive implementation by developing and implementing lifecycle management plans.

Implementation Approach

As a starting point, this guide identifies four basic steps for planning, implementing, and institutionalizing an asset management improvement program (see Figure 5-1).

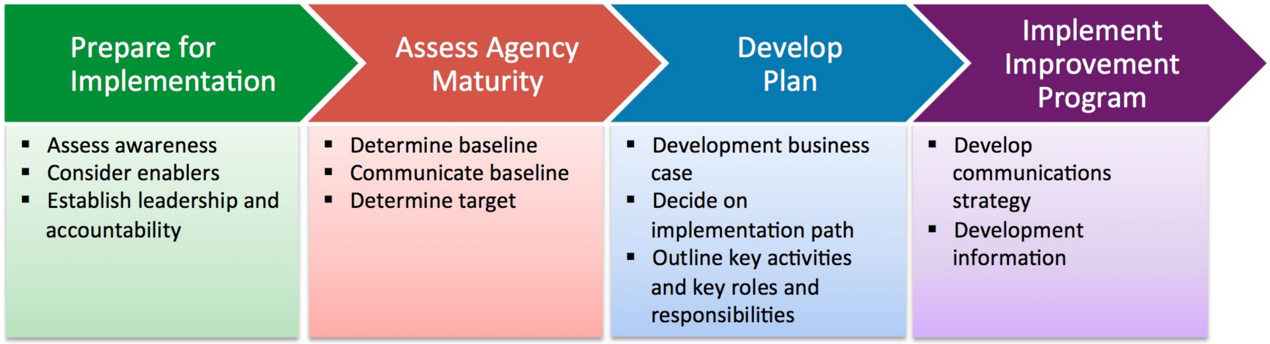


Figure 5-1 *Asset Management Implementation Program Approach*

These steps include:

- **Prepare for Implementation** – The best starting point for developing an asset management improvement program is to know the level of asset management awareness and understanding within your agency. By establishing a leadership and accountability framework and considering the change management required in the areas of training, communications, and values and culture (all implementation enablers listed in Table 5 1), the agency can establish a foundation for the asset management improvement program.
- **Assess Agency Maturity** – An important next step is completing an appraisal of the maturity of your agency's asset management processes. This means assessing which elements of the asset management process outlined in this guide you have in place and what role they play in your organization. This can provide a baseline describing your current process and be used to set improvement targets.
- **Develop a Plan** – The plan specifies the implementing actions for increasing asset management maturity, and outlines exactly how the agency will improve asset management processes and outcomes. The plan addresses your agency's awareness of asset management, readiness for change, and ambitions for the asset management improvement program. The plan should include funded improvement projects; therefore, to accomplish this, the plan must be coordinated with or addressed in the budget process.
- **Implement Improvement Program** – With all foundational items in place, the asset management improvement program can be implemented.

The rest of this section describes each of these activities in more detail.

What is an Asset Management Implementation Program?

Establishing progress towards the routine use of the business processes in the Transit Asset Management framework

- Based on direction provided by transit agency management
- Implemented by staff responsible for the lifecycle management of all transit assets
- With a focus on activities that are cost , risk , and performance driven agency wide, consistent condition assessment monitoring and reporting

Prepare for Implementation

The foundational activities associated with implementing and institutionalizing an asset management improvement program includes the following:

- Assess the asset management awareness in the agency.
- Consider asset management enablers.
- Establish a leadership and accountability structure.

Each of these steps is described in more detail below.

Assess Asset Management Awareness

Asset management awareness refers to an agency's board, management, and staff understanding of what asset management is, why it is important, and how their activity supports it. All transit agencies manage assets; however, the degree and depth that lifecycle asset management is understood throughout an organization informs the level of asset management awareness.

Do all of these staff members understand that they are supporting the asset management initiative?

- A general manager regularly asks for performance metrics around some of the more critical assets' performance.
- A procurement officer checks with engineering to see if lifecycle data (reflecting, for example, maintenance requirements) are incorporated into vehicle procurement.
- A maintenance manager decides to proactively replace all of the light bulbs in a facility at once because one failure likely means the others will fail soon.

The level of asset management awareness in an agency directly correlates with how ready the agency is for implementing an asset management improvement program. The more agency managers and staff understand what asset management is, its potential for improving performance, and how it relates to their job, the more likely they will be to support and encourage it. Establishing a common understanding of what asset management is and having a common language within the agency are prerequisites for success and should be addressed as foundational building blocks in implementation planning.

Consider Asset Management Enablers

Enablers are supportive processes and activities that form the foundation of a successful asset management improvement program. Displayed as the bottom panel in the asset management framework introduced in Section 2 (Figure 5-2), enablers ensure that the asset management business processes can be successful. Many of the enablers require dedicated resources (staff and/or funding); however, in many cases, these resources can be integrated into an agency's existing enabling processes.

Figure 5-2

Asset Management Enablers

Enablers

- Leadership & Accountability
- Training
- Communications
- Values and Culture
- Project Management
- Continuous Improvement

Table 5-1 describes the importance and success factors associated with each enabler. An agency should consider whether the enablers described in this table are in place and fully supportive of the asset management improvement program.

Table 5-1 *Asset Management Enablers*

Enabler	Relationship to Implementation	Success Factors
Leadership and Accountability	In many agencies, focusing the business practices around improved asset management can require a change in the way the agency does business. This means leadership provides clear direction regarding people's responsibilities. They also provide appropriate accountability mechanisms and develop and follow a structured communications strategy.	• Define asset management roles, responsibilities and accountabilities. • Document expectations for asset management in performance plans and applicable job descriptions. • Hold all stakeholders accountable for achieving the agency's asset management goals.
Training	Training enables staff to understand what asset management, why it is important, and how it can be improved.	• Train agency staff on the benefits of asset management and what it entails. • Develop asset management competencies within the organization. • Document asset management business processes to ensure that asset management skills and quality are maintained.
Communications	The asset management change initiative requires effective communications by leadership regarding their expectations, the implementation steps, and progress.	• Develop a communication plan that uses, to the extent possible, existing communication channels. • Encourage two-way dialogue and engagement that enables effective implementation.
Values and Culture	Culture in many ways is linked to an agency "saying what is important" and "doing what it says is important" and then "rewarding and recognizing supportive actions." Culture is established and/or reinforced by the leadership's actions and values. This includes how the agency recognizes and rewards positive and negative behavior, communicating and learning from negative feedback, and using data to drive management decisions.	• Before undertaking any asset management improvement program, take stock of the agency's current culture and values. Acknowledge those aspects of the existing culture that are supportive and those that could interfere. • Encourage and incentivize positive behaviors. • Hire management and staff who embrace the culture and values that are important to your agency. For example, an agency may focus on hires that have strong communication skills or have experience working across multiple departments, in addition to the other qualifications necessary for the position.
Project Management	Ensure that the asset management improvement program is managed based on sound project management practices. Emphasis should be focused on having strong tailored governance and communications. Adaptive program and project management may work well for your agency; this means applying lessons learned elsewhere.	• Assign project managers who have a strong grasp of asset management. • Encourage project managers to "own" asset management and drive change.
Continuous Improvement	Asset management is a process and requires a constant focus on improved performance and managed risk. To institutionalize this mindset, management and staff work to improve their data management and decision-making processes.	• Monitor outcomes and progress towards meeting asset management goals. • Empower and motivate staff to be innovative and feel ownership over their jobs. Staff can be empowered by asking for their feedback, incorporating their ideas into the solutions, and celebrating their successes.

Establish Leadership and Accountability

Leadership and accountability are important enablers. As part of preparing for implementation, the governance structure must be established for the asset management improvement program. The nature of the governance structure will differ between agencies, but it should provide clear direction regarding responsibilities, accountability, change management, issue resolution, and roles for communications strategy. This is important because an asset management improvement program is, ultimately, a linked series of smaller projects that drive agency-wide change. To be successful, an agency must have the leadership and governance structure in place to manage these projects.

Asset management implementation is most successful with an Executive Sponsor and Champion. Whether these individuals exist in your agency, the person or department leading the efforts to establish and implement an asset management improvement program should evaluate the following questions:

- Is the asset management initiative going to be an agency-wide change initiative or is it likely to "start small" and grow more pervasive over time?
- Does the asset management improvement program have board support?
- Does the asset management improvement program have Executive Level support and/or a Champion?
- What resources are required to support the asset management improvement program, are they available, and how can they be budgeted?

The answers to these questions will determine the level of resources needed for the asset management improvement program. The following are some of the key leadership roles and responsibilities for managing implementation:

- **Asset Management Executive Sponsor** – From the Executive Team, the asset management executive sponsor encourages and empowers other leaders and staff in the organization to drive the asset management improvement program forward. The executive sponsor communicates with the rest of the Executive Team, the board, and other stakeholders, as needed, to ensure that asset management is getting the attention and resources needed to ensure its success.
- **Asset Management Champion** – Agencies with successful asset management improvement programs have noted the importance of having an executive sponsor; however, if there is no or limited executive sponsorship, an Asset Management Champion can still drive the asset management improvement program. An asset management champion, not necessarily from the Executive Team, may become the "face" of the initiative and provide a resource for others in the agency as obstacles and challenges are confronted. This is an important position in the earlier stages of an asset management improvement program and should, ideally, remain so until changes have been institutionalized.

- **Asset Management Program Manager** – The Asset Management Champion may also own the management of the asset management improvement program. Whether he or she is partially or fully dedicated to the asset management improvement program, the Asset Management Program Manager should have asset management responsibilities written into their roles and responsibilities. They may be the same as the Asset Management Champion listed above. This person should be held accountable for developing and maintaining the asset management plan, communicating with the Executive Team, leading the Asset Management Improvement Team (defined below), and managing internal and external communications regarding the asset management improvement program. Ideally, this position, reports to the most-senior level to ensure the appropriate decision-making authority across departments and to ensure that the plan reflects enterprise-level priorities. Key competencies required to perform this role include the following:
  - Strong leadership, change management, collaborative, and project management abilities with broad respect throughout the agency
  - Broad transit exposure/knowledge to operations, maintenance, capital planning, and/or engineering
  - Knowledge about assets' lifecycle needs, including costs, performance implications, and risks
  - Excellent communication skills, including experience with board presentations, strength in facilitation, and experience in persuasion and influencing others
  - Political acumen and ability to relate well to stakeholders and staff at all levels within the agency
- **Asset Management Improvement Team** – Comprising representatives from maintenance, operations, engineering, finance, capital planning, information technology, and other related departments, this group should be the asset management knowledge and practice leadership for the organization. Reporting to the Executive Team, the members of this cross-functional team represent their department's technical expertise and interests; however, they will likely not be dedicated solely to the asset management improvement program. With clearly communicated performance and time expectations, this group's role is to manage across transit agency departmental silos, support the change management initiative, and improve communications both within and between departments. This group is responsible for vetting the asset management plan, leading its implementation, developing lifecycle management plans, compiling and communicating best practices, and supporting all enterprise-level asset management activities, including capital programming and operations and maintenance budgeting. They will likely be the owners of improved processes or have the changes incorporated in the work of their units.

The roles and responsibilities for an asset management improvement organization are described in Table 5-2, which provides a starting point for defining asset management implementation roles and responsibilities by function.

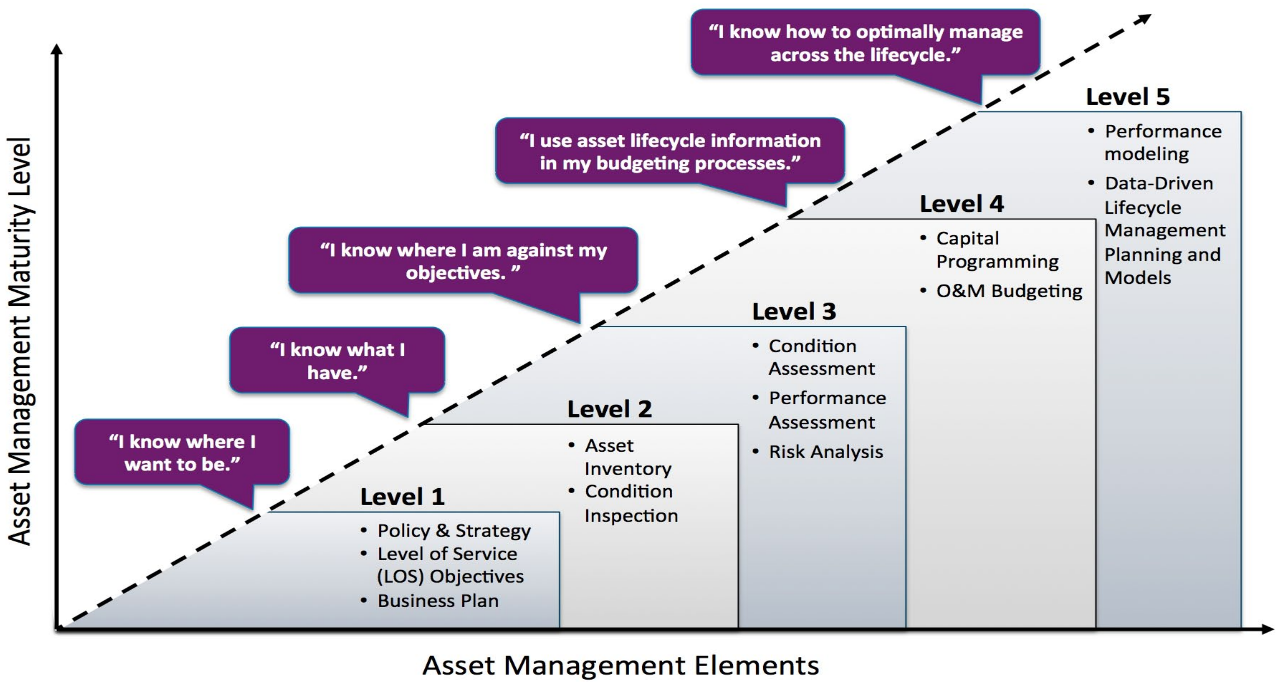
Table 5-2 *Asset Management Implementation Program Roles and Responsibilities*

Organization Function	Roles and Responsibilities
Board Members/ General Manager	• Approves the asset management policies, strategy, and plan. • Provides overall accountability for addressing the asset management objectives.
Executive Team (including Executive Sponsor)	• Establishes the policies, strategies, and level-of-service requirements for the organization. • Dedicates appropriate resources to ensure asset management improvement programs can be successful. • Provides the leadership necessary to drive organizational change and communicate the benefits of asset management. • Enforces strong accountability measures to encourage follow-through of the asset management strategy.
Asset Management Program Manager	• Leads the development and implementation of the asset management plan. • Coordinates all enterprise-level asset management activities and ensures all asset-level activities are supportive of the overall asset management strategy. • Leads the Asset Management Improvement Team to ensure cooperation and liaising between the different departments and business functions. • Communicates asset management activities, accomplishments, challenges, risks, etc to relevant stakeholders.
Asset Management Improvement Team	• Asset management experts and leaders in their respective disciplines. • Responsible for developing and sharing asset management best practices throughout the organization. • Responsible for vetting the asset management plan, leading its implementation, developing lifecycle management plans, compiling and communicating best practices, and supporting all enterprise-level asset management activities.
Asset Owners	• Leads the development and implementation of the asset lifecycle management plans and ensures these plans support the overall asset management strategy. • Collects and maintains appropriate asset data to support asset management business processes.
Department Heads (for example, Engineering, Capital Program Development, Budgeting, Planning, Finance)	• Provides the leadership and accountability to ensure that all business processes associated with asset management are supportive of the overall asset management strategy.
Line Staff	• As the key asset management plan implementers, these individuals should conduct day-to-day responsibilities with an understanding of how they support the asset management strategy.

Assess Agency Maturity

Asset management maturity refers to an agency's level of asset management practice. To build the asset management improvement program, it is necessary to establish a basic understanding of the level of asset management maturity within the agency.

An agency's asset management maturity may be as basic as understanding what assets it owns; however, a more mature asset management agency will be able to use that asset information to model different funding scenarios and optimally allocate funding to its assets. Figure 5-3 depicts a simplified approach to characterizing an agency's asset management maturity with five levels. Each level is described in more detail below the figure.



Note: A complete asset management program will have all levels functioning well; however, it is not unusual for an agency to conduct asset management activities that span all of these maturity levels at one time or to have skipped some levels while performing activities at another level. For example, many agencies have one or more asset inventories in place without any asset management policies or strategies.

Figure 5-3 *Understanding Asset Management Maturity in the Transit Industry*

The following list provides an overview of the asset management maturity levels:

- **Level 1** – At this basic level, an agency has a clear asset management vision. This includes a policy statement that provides top-down direction regarding asset management expectations, a strategy that outlines the approach for accomplishing the policy, and a plan that details the people, activities, and resources needed for addressing the policy and strategy.
- **Level 2** – At this level, an agency has one or more asset inventories with condition data that support multiple business processes. All of this data has a clear owner and process for maintaining its integrity.
- **Level 3** – At this level, an agency can conduct a risk analysis and/or performance assessment to evaluate the assets' current performance to evaluate how well the policy and strategy objectives are being met.

- **Level 4** – At this level, an agency can set priorities among and across all asset classes based on risk and performance data. This can inform the development of the capital program and operations and maintenance budget.
- **Level 5** – At this level, an agency can utilize performance modeling and other analytical tools to optimize how funding is allocated across and within all asset classes.

Determine an Agency's Asset Management Baseline

Assessing the agency's current state of asset management maturity provides a baseline that characterizes the current state of practice. This type of maturity assessment can be used to identify the gap between current practices and best practice, as identified in this guide. The gap will likely be different for different asset classes. This type of gap analysis can be used by an agency to identify the next steps and build an implementation path for improving maturity. This provides the basis for developing an agency's asset management plan.

To support this analysis, this guide's appendix provides a *Transit Asset Management Maturity Agency Self-Assessment*.[17] The assessment is designed to be used by an agency to determine its current state, or baseline, of asset management maturity. The self-assessment is intended to be taken by the Asset Management Improvement Team to ensure it reflects input from departments throughout the agency.

As its name suggests, the Transit Asset Management Maturity Agency Self Assessment provided in this guide was created to address the unique attributes of the transit industry. The assessment is designed to be used by an agency to determine its current state of asset management maturity. This assessment evaluates asset management maturity on three dimensions:

- Level of understanding
- Awareness
- Deployment of the process and practices of the asset management framework described in this manual

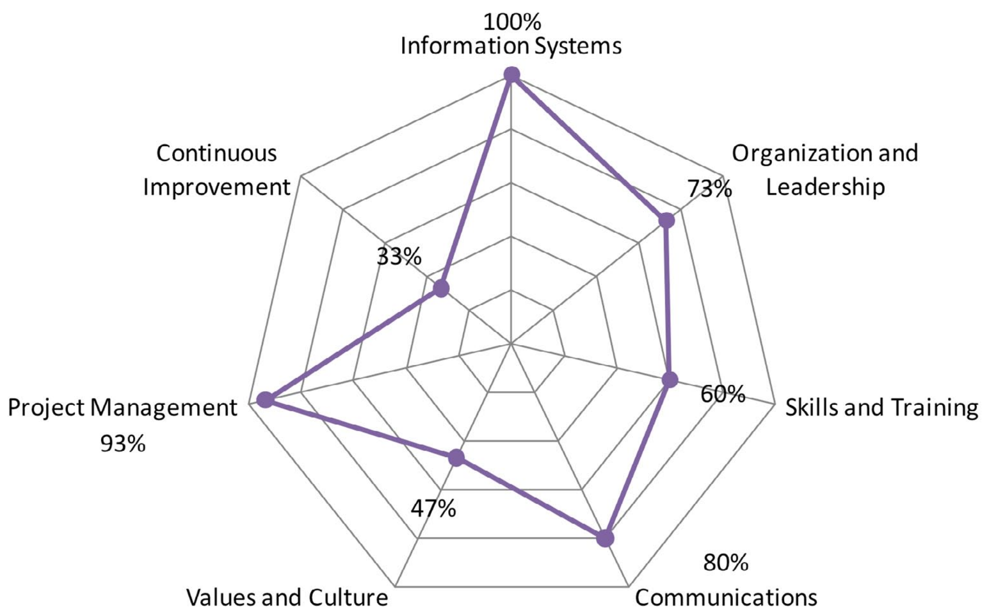
[17] PAS55, published by the British Standards Institute, has been adopted by utilities, transport, mining, process, and manufacturing industries worldwide. It provides an asset management self-assessment tool. While this tool will likely provide useful insight into an agency's level of asset management maturity, it was created to support a broad array of industries.

The *Transit Asset Management Maturity Agency Self-Assessment* (Appendix B) provides assessments in three major areas:

- **Overall Maturity Score** – The self-assessment tool presents an agency's score in each of the five maturity levels described in Figure 5-4.
- **Enterprise-Level Framework Scores** – The self-assessment tool presents an agency's maturity score in each of the nine business processes outlined in Section 3, and information systems and each of the enablers discussed in Sections 4 and 5, respectively (see Figure 5-4 for a sample output).
- **Asset Class-Level Framework Scores** – The self-assessment tool presents an agency's maturity score in each of the asset classes presented in Section 5.

Figure 5-4

Transit Asset Management Maturity Agency Self-Assessment *Sample Output*



Communicate the Asset Management Baseline

As described in Section 5, Assess Asset Management Awareness, the increased level of asset management awareness in an agency directly correlates with how ready the agency is for implementing an asset management improvement program. The Asset Management Program Manager can enhance the management and staff's asset management awareness by sharing the results of the self-assessment. This will educate staff on what asset management is in the context of existing agency practices, and it is intended to get everyone "on the same page" using a common language. By potentially supplementing the communication of the baseline with broader asset management training, it will also provide the basis for the business case (presented later in this section).

It is important that this information is communicated in a way that recognizes the agency's existing good practices and presents shortfalls as opportunities for improvement. Asset management is a process and is performance-based, so agencies should always have opportunities for improved reliability, customer service, and cost savings.

Determine an Agency's Asset Management Target

As stated in Level 1 of the asset management maturity scale, an agency should have established expectations regarding "where the agency wants to be." An agency's target may be to achieve a maturity rating of Level 4 within 5 years, or have all of its assets having a minimum condition score of 3 out of 5, or to have a "best in class" process or to be a "global leader" in transit asset management. Ideally, this agency's asset management target is established by the Executive Team and may be memorialized in the form of an agency-wide policy statement. No matter what the objective is, or who is generating it, it is important for an agency to have and communicate a target that it can be evaluated against as resources are invested and progress is made.

Develop the Plan

As described in Section 3, the plan specifies the implementing actions for increasing asset management maturity. It outlines exactly how the agency will meet its target in the context of the agency's awareness of asset management, readiness for change, and ambitions for the asset management improvement program. This section provides guidance on developing the business case for asset management, selecting an implementation path for an agency, outlining the key activities, and assigning roles and responsibilities for the planned year. These are important steps for an agency at the beginning of an asset management improvement program. It is good practice to reassess the implementation plan periodically and update the plan to align with the budget process.

Develop an Asset Management Business Case

An asset management business case is the statement of the anticipated impact that the implementation of the asset management improvement program will have on the performance of the agency. A compelling business case demonstrates improved productivity, cost savings/avoidance, and risk management. Peer examples can help to "make the case."

> An asset management business case explains how the expected outcomes provide a cost effective accomplishment of reliability, safety, customer service, and cost performance management.

Business case analysis "makes the case" to management for approving and allocating resources to the implementation of the initiative. Such analysis is important because it ensures that the implementation supports the business objectives of the agency and can provide an effective mechanism for building support and communicating the importance of the initiative.

This is an important step because it brings rigor to the development of the implementation program and provides accountability for the investments required for implementation, especially if there are any near-term impacts on productivity caused by reallocation of staff time to asset management activities. Additionally, the communication of existing agency issues and risks and the potential outcomes associated with an asset management improvement program will likely prove to be very powerful as the initiative requires significant stakeholder support.

An agency may already have a standard approach to developing a business case, return on investment analysis, or feasibility study for new initiatives. In general, the following elements or analysis considerations are typical components of a business case:

- A concise description of the "deliverable" resulting from implementation, with other supporting description of what is to be implemented.
- Implementation steps.
- Major business changes required.
- Required resources (including staff and funding).
- Estimated benefits expressed in terms of the resultant outcomes. Ideally these align with the agency's performance management objectives and address, reliability, safety, customer service, and lifecycle cost metrics.
- Risks to the accomplishment of the outcomes. This is an important consideration because risks can arise from a variety of internal and external sources. An approach that identifies risk, assesses the risks, and identifies a risk management plan is a recommended practice.

The business case analysis enables management to consider the benefits, costs, and risks of assigning resources to implement the asset management improvement program and its constituent projects.

Agencies will approach asset management implementation in varying ways; this guide identifies three general implementation paths to consider when getting an asset management improvement program started. A key to success in implementing change of this type is clarity on the vision, the outcomes to be accomplished, and having the flexibility to be adaptive as the agency learns and an agency's operating environment changes. Over time, an agency will establish its own path but may use these as a start.

Decide on Implementation Path

The prior steps provide the basis for developing an overall implementation program. With a common understanding and agreement regarding the current state of asset management within the agency, the Asset Management Improvement Team can develop an implementation path comprising individual asset management improvement projects.

The implementation paths are characterized in Table 5-3. The following pages provide more detail, including an overview of that path's characteristics, benefits, attributes of agencies that may be best suited for this path, and a high-level implementation schedule with key activities.

In general, Path #1: Enterprise-Driven provides the most comprehensive opportunity to improve overall asset management practice, institutionalize its use, and yield all of the business benefits. However, it is understood that organizational context may make this a higher risk option due to lack of resources, limited executive sponsorship, lack of a champion, or other considerations. If that is the case, elements of this implementation path may be incorporated over time as an agency accomplishes success through a different path.

Three potential implementation paths are identified in this guide as a starting for developing a path for your agency (Path #1: Enterprise Driven, Path #2: Asset Class Driven and Path #3: Capital Planning Driven). They are provided as strategies for implementing a series of improvement projects that individually and in concert will improve asset management maturity.

The resource requirements to implement an asset management improvement program will vary between agencies depending on their size, maturity, and implementation paths. This guidance cannot estimate resources necessary to complete an implementation task; however, the identified timeframe provides general guidance on the level of complexity and resources required to complete that activity. These will vary significantly depending on the size of the agency, the agency's level of asset management maturity, and the level of resources committed to the asset management improvement program. An agency should develop the level of resources and timing for all projects that comprise the asset management improvement program and use this information in its business case analysis.

Table 5-3

Potential Asset Management Implementation Paths

Potential Implementation Paths	Path Characteristics	Attributes of Agency Interested in Path
#1: Enterprise-Driven	• Enterprise initiative that starts by establishing asset management policies, strategy, and a plan that ensures a well-integrated and aligned organization. • Uses consistent, up-to-date, and increasingly complete asset inventory data to align with the agency's performance management requirements and support all enterprise-level asset management business processes. • Requires strong executive sponsorship commitment to asset management being one of the agency's top strategic objectives. • Staff at all levels increasingly understand how their job supports asset management.	• Any size agency with any mix of modes or ages of assets. • Asset Management Champion is the Executive Level sponsor. • Staff dedicated to the asset management improvement program (full- or part-time, depending on the size of the agency). • Dedicated resources available to drive implementation, including software investment. • Agency management and staff understand.
#2: Asset Class-Driven	• Driven by the managers of individual asset classes who champion asset management; it does not require enterprise-level direction. • Improvements focus on the lifecycle management of individual asset classes. • Key to this implementation path is the development of lifecycle management plans for those assets within the classes involved (starting with the most critical assets).	• Single- or multiple-mode agency with assets of any ages. • Asset management champion does not necessarily exist at Executive Level. • Staff are most likely not dedicated to an asset management improvement program.
#3: Capital Planning-Driven	• Focuses on providing information on asset condition from a centralized asset inventory in a consistent way across all asset classes. Information can be used to improve programming and prioritization to improve asset management outcomes. • Capital improvements required to meet the level of service commitments are systematically identified and communicated. • Focus of this implementation path is more at the planning level, but it can provide a springboard for increasing awareness and then driving initiative and methods to reduce lifecycle costs.	• Single- or multiple-mode agency with assets of any ages. • Asset management champion does not necessarily exist at Executive Level. • Staff are most likely not dedicated to an asset management improvement program. • Agency management and/or staff recognize the need to prioritize the capital program in a more transparent, systematic way to more effectively use capital funds. • Some consultant support and software investment may be required.

Implementation Path #1: Enterprise-Driven

This path requires an executive commitment that makes asset management one of the agency's top strategic objectives. Ideally this is not seen as an "asset management improvement program"; it is just the way the agency does business. It is an enterprise initiative that starts by establishing asset management policies, strategy, and a plan that ensures a well-integrated and aligned organization. This path uses consistent, up-to-date, and complete asset inventory data to align with the agency's performance management requirements and support all enterprise-level asset management business processes. Staff, at all levels, understand how their jobs support asset management and the agency as a whole is constantly looking for opportunities for improvement. Figure 5-5 illustrates the broad elements and timeline for the enterprise-driven implementation path.

Figure 5-5 *Implementation Path #1 (Enterprise-Driven) Summary Activities and Schedule*

Potential Short Term Improvement Activities Associated with Implementation Path #1

- Detailed plan provides transparency for stakeholders and clear direction for all staff and management
- Clear business targets can improve accountability and performance
- Centralized inventory provides simplified access to comprehensive, reliable data to support agency decision making and asset valuation
- Centralization of processes requires traditionally siloed departments to work together, which can improve coordination and communication
- Lifecycle management plans (focusing on the most critical assets first) can help an agency to minimize the lifecycle costs and improve assets' performance

Implementation Path Characteristics

- Requires Executive Level direction-setting and guidance.
- May require significant agency change, including changes to roles and responsibilities, business processes, and overall culture.
- Requires consistent, dedicated staff and funding resources over long term.
- Full benefits will likely not be realized for a number of years; however, short-term benefits exist.

Benefits

This implementation path has the potential to provide an agency with the following benefits:

- Improve an agency's performance and cost-effectiveness.
- Optimize funding allocations in addition to improving stakeholder communications.
- Transform the entire agency's culture towards an asset management focus.
- Drive cultural change by causing a ripple effect of staff empowerment and accountability.
- Provide transparency in decision-making at all levels.
- Improve communications both within the agency (internally) and with stakeholders (externally).

Attributes of Agency Interested in this Implementation Path

- Asset Management Champion exists at Executive Level.
- Full-time staff dedicated to the asset management improvement program (level of staff resources dependent on maturity of agency's asset management activities and number of agency's assets).

- Dedicated resources available to drive implementation, which will likely include software investment.

Examples of short term "wins" might include the following:

- Collaboration in decision making across traditionally siloed groups (for example, engineering, finance, operations, maintenance, and procurement) to elevate consideration of lifecycle costs (supportive of all Implementation Paths).
- Aligning maintenance, operations and capital planning and programming to improve reliability.
- Managing against enterprise performance metrics for reliability.
- Updating asset inventory to include all critical assets first and sub components (supportive of all Implementation Paths).

The enterprise-driven implementation path will likely take more than three years to fully realize its benefits, as illustrated in Figure 5-5. Leadership is needed to drive the change and communicate internally and externally, resources must be dedicated to ensure the strategy is supported, and information systems will likely be developed and integrated to manage the data and analysis. A successful agency will be one that holds itself accountable for improving performance continually whether the focus is on improving reliability, reducing lifecycle cost for delivering the same level of service, and/or improving customer service.

Case Study

Chicago Transit Authority (CTA) – Chicago, IL

Relevance of Case Study

This case study illustrates how the Chicago Transit Authority (CTA) is implementing a comprehensive asset management system for use in managing its facilities and track-related assets. The improved system, once implemented, will provide CTA staff with better data on their assets, and reduce the extent of duplication between multiple management systems implemented for managing different assets.

Agency Overview

CTA is the second largest public transportation system in the United States, serving 3.8 million people within the city of Chicago and 40 neighboring suburbs. The agency was formed in 1947 with the acquisition of the Chicago Rapid Transit Company and the Chicago Surface Lines. In 1952, the CTA expanded to include the Chicago Motor Coach system. Today, CTA's assets include:

- 1,781 buses traveling 140 routes and covering 1,959 route miles.
- 1,200 rail cars traveling along 224.1 miles of track between 145 stations.
- Numerous maintenance and support facilities.

CTA ridership averages 1.6 million rides per weekday and 516.87 million rides each year.

Asset Management Implementation Approach

Through the 2010 FTA Bus State of Good Repair Program CTA received a $5.4 million grant to implement an improved transit asset management solution. The grant initially focused on bus facilities, but following conversations with FTA, CTA expanded the scope of the effort to incorporate other fixed assets, most notably rail maintenance facilities and stations. Four phases of work are planned as part of this effort:

- **Phase A (Ongoing): Enterprise asset management system enhancement and data migration**. Assets from the 1992 inventory and existing database are being incorporated into the enterprise asset management system. As part of this effort, CTA established a hierarchy for its assets, choosing the level at which each item should be considered an asset versus a component of an asset. For each asset required fields, such as age, quantity, location, and replacement costs were added to the database structure, along with placeholder fields for condition data that can be tracked over time. CTA began the project by focusing on facilities data, but has expanded the effort to incorporate rail maintenance facilities and stations, which will be used as a template for incorporating additional data into the system at a later date.

- **Phase B (Ongoing): Facility asset inventory and assessment**. The engineering field condition assessment portion of this project provides for multi-disciplinary teams of engineers to survey and rate the current condition of select facilities. Engineers will also develop recommendations for future data collection, suggesting standardized methods, timeframes, and triggers that should prompt further reviews. During this time, CTA will develop asset maintenance cost estimates that can be incorporated into the database. This phase is scheduled for the summer of 2012.
- **Phase C (Planned): Create reporting and modeling capabilities**. CTA will add reporting capabilities to use in making policy and planning decisions. The reporting and modeling tools will allow CTA to assign priorities to projects based on criteria such as age, condition, safety and reliability impact. CTA also intends to incorporate information in the reports on maintenance work orders, including actual maintenance costs and measured maintenance impact on operations.
- **Phase D (Planned): Develop a plan to maintain asset information over time**. During this final phase, CTA will prepare a plan to ensure that the data in the enterprise asset management are maintained and do not become obsolete. Data owners will be assigned to manage subsections of the data, allowing discrepancies to be reconciled and ensuring that the data are carefully updated. This will allow CTA to use the system to its utmost benefit in the decision-making process.

CTA began work on the project in 2011, and has committed to an overall project schedule of twenty-four (24) months from grant award (May 9, 2011) to delivery of required deliverables. All four phases, including training end-users and recommendations for ongoing maintenance, are to be completed within that time period.

Benefits/Outcomes

In the past, CTA has used multiple management systems concurrently, creating a fractured system for data collection, storage, and analysis. By eventually combining asset data into a streamlined set of systems, CTA expects to improve its asset data, better support a data-driven approach to asset maintenance and management, and minimize the costs of data management.

The expectation is that the following will be accomplished during the project:

- Develop enhancements to the enterprise asset management system to allow for a centralized data repository that multiple departments can access and utilize
- Consolidate appropriate CTA facility asset information from legacy sources into the enterprise asset management system
- Perform assessments of critical assets for facilities under study and migrate the information into enterprise asset management
- Provide functionality within the enterprise asset management system to create reports that summarize collected asset data
- Review and make recommendations for CTA process improvements associated with the use of the enterprise asset management system
- Develop and train CTA staff regarding the approach for CTA to update the information on a rolling basis

Lessons Learned

CTA's experience has demonstrated the importance of having a plan and information systems established to maintain asset data. Without these crucial elements it is unlikely that agency staff will fully utilize asset inventory and condition data that are collected. Further, absent a comprehensive asset management system, there is a tendency for information systems to proliferate, resulting in multiple, costly, overlapping information systems. At the same time, however, CTA's experience shows that it is often possible to leverage an existing asset management system to customize what data they store, and expand these systems to multiple asset types, reducing the need for duplicative systems.

Sources and Other Resources

Information provided by a senior contact at CTA.

Implementation Path #2: Asset Class-Driven

This implementation path is most likely driven by one or more of the managers of individual asset classes or a department who provides leadership and champions asset management. The implementation path does not require enterprise-level direction. A line manager can apply the principles in this guide to their sphere of responsibilities and apply the leadership and influence they have as a "good manager" to move the agency forward and drive change in their sphere of influence. The focus is less on the enterprise-level activities and more on the lifecycle management of individual asset classes. The key to this implementation path is the development of lifecycle management plans for each asset (starting with the most critical assets).

While this implementation path is not an agency-wide initiative, it can support an agency-wide initiative if and when that decision is made. An agency that has a good example of asset management happening for one asset class can use that to demonstrate the positive outcomes of improved asset management. Additionally, they can replicate that model for other assets and communicate both the challenges and lessons learned.

Implementation Path Characteristics

- Asset owners lead the asset management improvement program for their respective asset class by establishing a team that manages across that asset's lifecycle.
- Cultural change is necessary for the managers and staff who "own" the asset class.
- May require some dedicated resources, but much less than Implementation Path #1: Enterprise-Driven.
- Benefits specific to the asset classes addressed may be realized in the short- to medium term.

Benefits

This implementation path has the potential to provide an agency with the following benefits:

- Improve the safety, reliability, and/or total cost of ownership of selected assets throughout their lifecycle while ensuring the most cost-effective investment strategies.
- Minimize the risk of failures associated with the selected asset classes.
- Make data-driven, informed investment decisions within that asset class.
- Improve internal communications by requiring cross-department coordination throughout the asset's lifecycle.
- Provides opportunity for establishing internal agency asset management best practice examples and demonstrates to other asset owners the benefits of an asset management initiative.
- Empowers middle managers to improve asset management practices, which can elevate their visibility and built support for a broader asset management improvement program

Attributes of Agency Interested in this Implementation Path

- Single or multiple-mode agency with assets of any ages or may begin based on new initiative (for example, new railcar procurement or rail line extension).

- Agency culture supports managers and technical leaders who innovate and drive business improvements.
- Executive level leadership may be necessary to ensure consistent lifecycle management plans across multiple asset classes.
- Staff are most likely not dedicated to an asset management improvement program; however, one or more staff may have a broader job description that requires them developing cross-functional groups with the responsibility of managing an asset throughout its lifecycle.

This initiative is driven by "asset owners," so it can start in one department where a manager champions and provides leadership or it can be implemented across multiple asset classes. It may begin with a focus on one asset class and, when the business benefits can be demonstrated for that asset class, the agency may decide to replicate that model for other asset classes. Or, the increased awareness across the agency may lead to a broader implementation program based on a different implementation path. The asset owners will need to develop lifecycle management plans (see Section 3) that reflect input from multiple departments. The agency may begin to realize the benefits of cross-departmental coordination and communication within months. Depending on the number of asset classes included in this initiative, it can take anywhere from 6 months to 3 years. Figure 5-6 index the type of implementing activities and schedule an asset class-driven implementation path that starts with one or more asset classes.

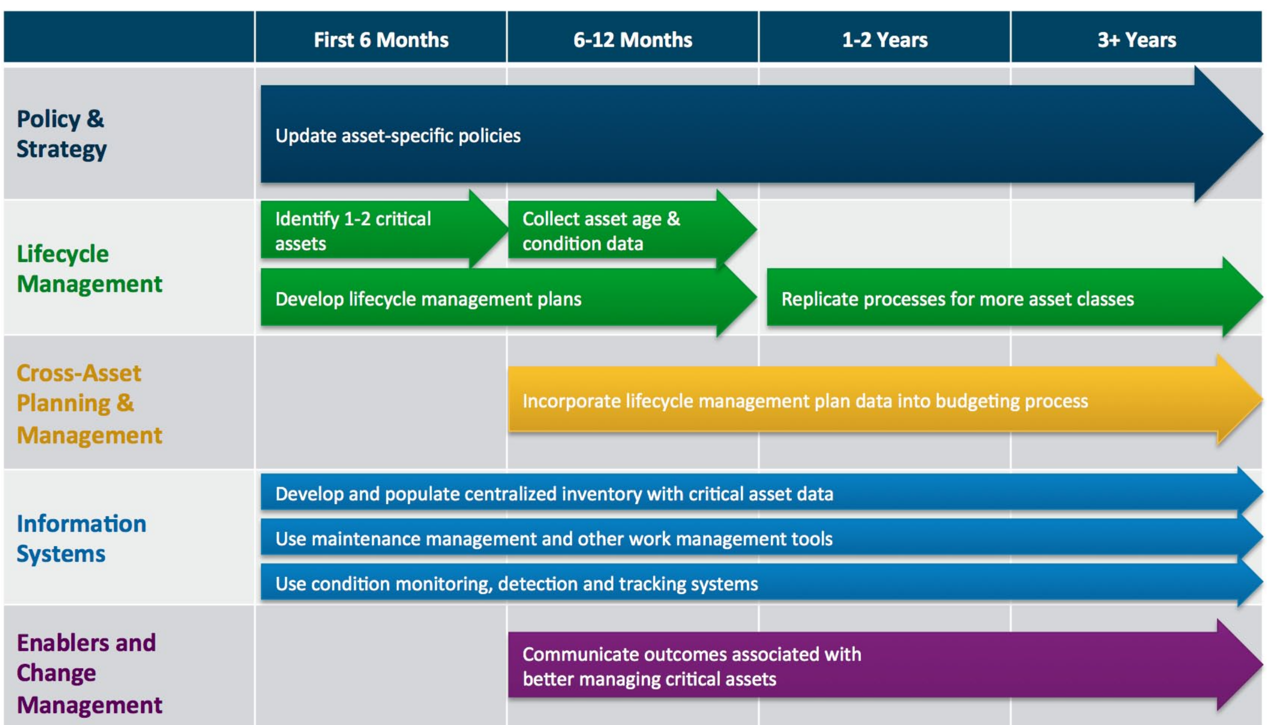


Figure 5-6 *Implementation Path #2 (Asset Class-Driven) Summary Activities and Schedule*

Case Study

Bay Area Rapid Transit District (BART)

Relevance of Case Study

This case study illustrates how one agency department can lead a successful asset management improvement program focused on one asset class. The Bay Area Rapid Transit District (BART) Railcar Maintenance group transformed the way their group conducted business to improve many performance metrics.

Agency Overview

BART is a heavy rail transit system serving the San Francisco Bay Area. BART operates five lines on 104 miles of track with 44 stations in four counties. With an average weekday ridership of 379,300 passengers, BART is the fifth-busiest heavy rail rapid transit system in the United States.

BART currently maintains 669 rail vehicles. This is the oldest fleet in the nation and has a utilization rate amongst the highest in the nation (based on peak commute hours). The agency is currently working on a $2.2 billion procurement of 750 new rail vehicles expected to be in production in 2017.

Asset Management Implementation Approach

In 2006, BART's started the Strategic Maintenance Program (SMP) in an effort to modernize processes and capitalize on lessons learned from the private sector. The desire to make change was driven by the realization that business as usual would not position an aging, heavily utilized railcar fleet to meet growing ridership and increasing service demand.

When initiated, the SMP vision was "To implement a continuously improving reliability-based maintenance process, which brings world-class maintenance practices to BART and its customers." The fundamentals of SMP were centered on the principles of reliability-centered maintenance (RCM), lean production efficiency, and continuous improvement. As SMP evolved from an initial program to new business as usual, the scope would grow to include a push towards more scheduled maintenance with expanded planning and scheduling capabilities; improved documentation, processes, and decision-making capabilities; expanded and targeted employee development and training; an evolution from quality control to quality assurance; and instilling a culture of ownership and responsibility at all levels of the organization. To that end, improvements were initiated in four key areas: people, processes, parts and systems. Each of these is described in more detail below.

- **People** – The SMP has put significant emphasis on staff development and ownership. Tamar Allen, Chief Maintenance Officer, stated "We changed the dialogue with the employees. We started to get the problems on the table and discuss them openly and freely without blame or recrimination. The objective was always about engaging the employees and ridding ourselves of the culture of "us against them." We encouraged our employees to be part of the solution, not part of the problem." Working together, the SMP team identified ways to improve maintenance processes, including changes to their work stations, tools, communication methods, etc. As part of this initiative, the SMP program formalized a centralized training program that has a curriculum-based training plan. Additionally, to encourage staff ownership, BART monitors and posts reliability performance by team. Each team lead is responsible for their performance. BART has clarified roles and responsibilities to improve accountability, supported by additional leadership training.
- **Processes** – The SMP has transformed the group towards an RCM program. This means that they have switched from a purely reactive maintenance philosophy to a planned production philosophy. Staff use data to establish maintenance cycle times and determine root cause of failures so that the maintenance program is continually improving. The group has reduced the time spent on unscheduled maintenance from >80% to <40% (even though they are still striving to achieve their target of 20% unscheduled and 80% scheduled). So, instead of constant "firefighting," staff works to scheduled work plans, which has created a more stable work environment and allows the work to occur most efficiently. Most processes have been documented in standardized work procedures, after thorough evaluation to determine best practice.
- **Parts** – BART's past procurement process took too long and had significant variation in the parts quality. Improvements include:
  - A supplier pre-qualification program allows BART to audit its suppliers and give BART recourse to address issues and reward good performance
  - A transformation to a demand-based stocking and distribution system, so parts are "pulled" from shops and not "pushed" from stores
  - Parts are centralized in a kitting area so filling a customer order now takes 3 minutes per caliper instead of 56 minutes.
- **Systems** – BART's desire to measure performance was limited by its information systems. In 2011, BART implemented a maintenance management system, integrated with its financials and administration system. The system is now stable, and beginning to produce beneficial performance reporting essential to the SMP strategy.

> Another key system improvement was the installation of wireless network enabled kiosks on the maintenance floor. These kiosks, along with wireless connectivity for technician laptops are providing the portal for immediate up-to-date documentation access for all employees, and has greatly facilitated adoption and utilization of the maintenance management system in the shops.

In addition to the focus on the maintenance of BART's existing vehicles, the SMP group has also provided significant input into the design of BART's new railcar procurement. The SMP group's input has focused on reliability, maintainability, and availability improvements that will support the agency's goals throughout the rail vehicles' lifecycle. The supplier will have to provide railcars that are "SMP-ready," which means they will facilitate on-boarding into the maintenance management system, and make sure the car configuration and parts work with their maintenance strategy. Other specifications include a detailed weight control program, energy efficiency program, vehicle climate chamber testing, and performance-based requirements, including minimum mean time to repair and availability requirements.

Benefits/Outcomes

BART's SMP has had significant measurable outcomes since the program's inception:

- Car maintenance issues went from being 45% of all system delays to 15%.
- As of 2012, car availability improved by 7.5% from 533 cars to 573.
- As of 2012, car reliability (measured based on mean time between service delays) improved by 180% from 1,444 hours to 3,216 hours.
- As of 2012, the number of maintenance workers (including mechanics and technicians) decreased by 26% from 442 employees to 350.
- As of 2012, the railcar maintenance program has shifted from >80% unscheduled/reactive work to <40%.
- Much of the repair work formerly outsourced is now done in-house; better, cheaper, faster.. Examples include AC traction motors, cables, and HVAC.

Qualitative benefits include:

- Improved morale and employee ownership due to the collaborative work environment and forward-focus
- Improved, more efficient work environment, designed by employees
- Inherent succession planning due to leadership training, Team Lead positions, and process documentation

- Inventory levels and lead times have been set to appropriate levels
- Improved partnerships both internal to BART and with external agencies

Sources and Other Resources

Information provided by a senior contact at BART.

Implementation Path #3: Capital Planning-Driven

This implementation path begins asset management improvement in the capital planning and programming process. The general approach is to provide systematic information on asset condition and capital needs required to meet the level of service or performance targets established for the asset condition (this is often referred to as the state of good repair). The approach to varying degrees establishes a link between condition and reliability performance. This implementation path focuses on providing information on asset condition from a centralized asset inventory in a consistent way across all asset classes. In this way, the capital improvements required to meet the level of service commitments are systematically identified and communicated. This provides a way to "tell the story" regarding the condition of an agency's assets and the performance consequences with different capital funding levels. This involves the development of a centralized inventory, the application of consistent condition measures across all assets, and the use of tools that prioritize all capital needs based on different levels of funding.

"Because of the time and resources involved to migrate an asset class into a formal asset management system, our agency has been undergoing this migration on an asset-by-asset basis."

– U.S. Transit Agency Manager
(Source: 2011 Parsons Brinckerhoff Survey)

The focus of this implementation path is more at the planning level, but it can provide a springboard for increasing awareness and then focusing more on other aspects of asset management. While this path involves enterprise-level direction, it does not necessarily consider the operations and maintenance costs or require organization-wide change. It does, however, identify the improvements required to address preventive and reactive maintenance backlogs and rehabilitation requirements—all of which can reduce lifecycle costs. This information allows for explicit consideration of resource allocation in the capital planning and programming process between pressing asset condition-related needs and other improvements.

Implementation Path Characteristics

- Requires changes to the capital planning and programming process, so many agency's functions will be exposed to some degree of business process improvement.
- Requires some dedicated resources, but much less than Implementation Path #1 (Enterprise-Driven).
- Executive-Level champion may be needed to drive consistency of capital needs measurement across asset classes and to encourage agency departments to share data; however, the leadership required is significantly less than Implementation Path #1 (Enterprise-Driven).
- Benefits may be realized within a couple of years depending on the agency's ability to compile appropriate data.

Benefits

This implementation path has the potential to provide an agency with the following benefits:

- Provides simplified access to comprehensive, reliable data to support agency decision-making and capital programming.
- Provides transparency in decision-making at all levels.
- Improves communications regarding the agency's capital needs, funding decisions, and scenarios reflecting the impact of different levels of capital funding within the agency (internally) and with stakeholders (externally).
- Justifies the level of investment needed to improve an agency's assets' condition and performance and the performance impacts of not receiving that level of funding.

Attributes of Agency Interested in this Implementation Path

- Single- or multiple-mode agency with assets of any ages.
- Asset management champion does not necessarily exist at Executive Level.
- Staff are most likely not dedicated to an asset management improvement program; however, staff are required to collect data (likely from many different sources) and incorporate into a scenario evaluation tool.
- Agency management and/or staff recognize the need to prioritize the capital program in a more transparent, systematic way to more effectively use capital funds.
- Depending on staff and information systems availability, some consultant support and software investment may be required.

This involves the development of a single inventory with the application of consistent condition measures across all assets, and the use of information systems that systematically prioritize the capital needs based on different levels of funding. As shown in Figure 5-7, the full implementation of this initiative can take more than three years; however, benefits are likely to be realized after a couple of years.

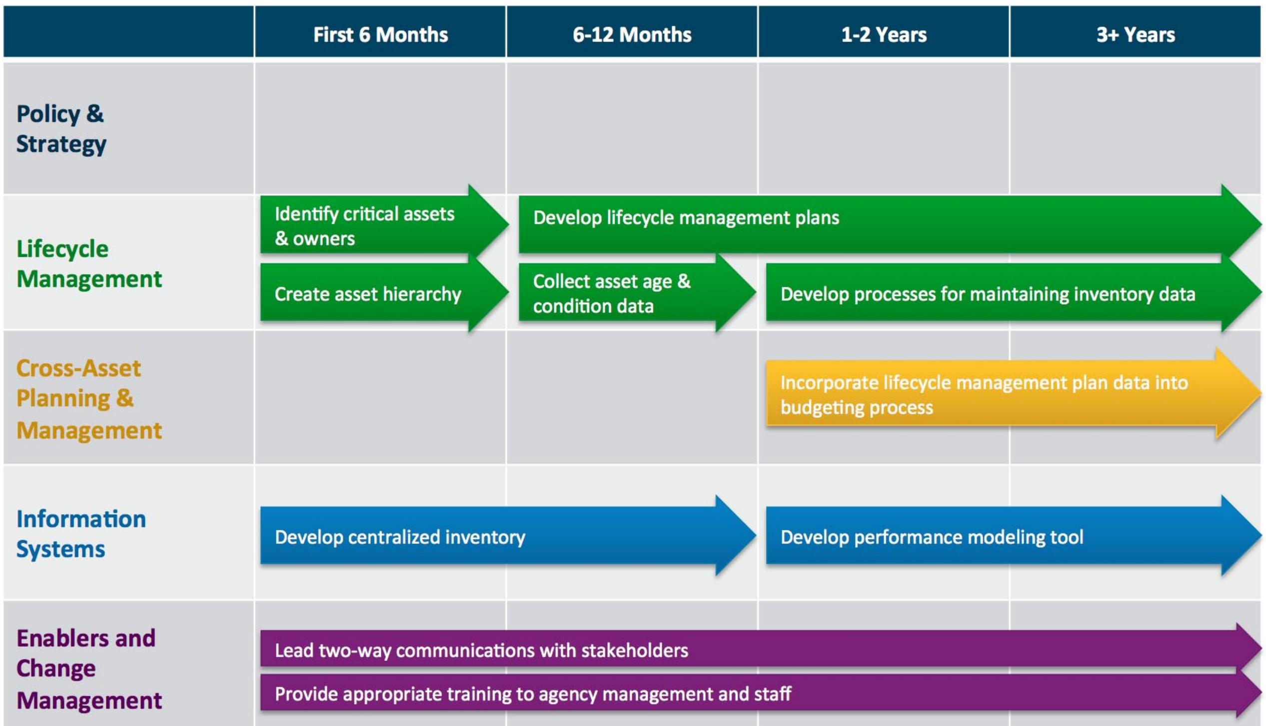


Figure 5-7 *Implementation Path #3 (Capital-Driven) Summary Activities and Schedule*

While Implementation Path #3 (Capital-Driven) includes the development of a single inventory and consistent condition measurement, the inventory is typically used to support the capital planning and programming function and does not provide the detail to support asset management activities at the maintainable unit level. So, the single inventory provides planning-level condition information such as a score (for example, on a scale of 1 to 5) for each of the agency's asset classes. In this way rail vehicles may have a condition score, but it may not provide information about the vehicles' subcomponents, their condition, past maintenance activities, and the replacement value. That detailed information is more likely to support the lifecycle management of the vehicle.

Case Study

Valley Transportation Authority (VTA) – Santa Clara, CA

Relevance of Case Study

This case study illustrates how the Santa Clara Valley Transportation Authority (VTA) implemented a Commercial-Off-the-Shelf (COTS) software package for use in project prioritization. The software provides VTA with an ability to better prioritize its projects considering agency goal and objectives, and do so using a documented, repeatable process.

Agency Overview

The Santa Clara VTA was created in 1972 to provide public transportation to Santa Clara County. The system serves a total of 326 square miles. VTA currently maintains the following assets:

- 450 active buses with an average age of 7½ years
- 75 routes covering 1,235 miles with 3,814 stops
- 99 light rail vehicles and 4 historic trolleys covering 42.2 route miles

In 2008, the Santa Clara VTA had an average of 106,673 weekday riders and an annual budget of $363 million.

Asset Management Implementation Approach

VTA's asset management efforts were initially triggered by the Metropolitan Transportation Commission (MTC) requirements for each San Francisco Bay Area transit property to submit asset data in support of the MTC Regional Transit Capital Inventory (RTCI). Previously VTA had basic information on its inventory, but found it had to supplement its inventory data with additional detail. Also, VTA was already using an enterprise resource planning (ERP) system for accounting and work order management, but this system was not used for maintaining detailed inventory data. As a result of its efforts to provide data for the RTCI, VTA developed a basic transit asset inventory that has formed the basis for subsequent transit asset management efforts.

An important catalyst for VTA's recent efforts to further improve its asset management data and tools was the Bay Area Rapid Transit (BART) extension to San Jose. As part of its work applying for FTA New Starts funding for this project, VTA was required to develop a 20-year financial plan detailing the costs of maintaining VTA's assets. Based on its initial analysis, VTA recognized that it required better data and tools for assessing its state-of-good repair needs. The agency then initiated an effort to better define what investments would be required to maintain a state of good repair for VTA assets, and to prioritize state-of-good-repair investments given available funds.

To help develop its financial plan VTA engaged a consultant to identify investments that may be required to achieve a state of good repair over a 20-year period, based on data collected for the RTCI and considering future asset deterioration. The consultant developed a list of 70 candidate capital projects, supplement a list of 26 projects previously identified by VTA. To develop the list of projects, VTA and the consultant grouped needs for individual assets into projects, as the agency found it more manageable to work with a consolidated set of larger projects than a large number of individual asset repairs.

In order to prioritize the set of projects for inclusion in the financial plan, VTA defined a set of basic factors to consider for each project. These include transit system preservation, system improvements, cost impact, enhancement of safety and security, environmental sustainability, and the ability to increase ridership. VTA technical staff evaluated the extent to each of the projects achieved agency goals with respect to these factors.

Once each project and its factors were defined, VTA used decision-making software to set weights on each of the prioritization factors and establish a prioritized list of projects. The system allows multiple users to create personalized prioritization scales and uses these scales to create composite weights that determine project rankings. The system also allows individuals to change the conditions and weights, creating flexible models than can provide new outputs if priorities change or budgets shift.

VTA assembled a set of 15 senior management personnel, representing all of the major departments. VTA technical staff reviewed each of the proposed projects, and agency managers created their prioritization scales for the projects. The process was an iterative one, with adjustments made following review of the rankings, until a consensus emerged on the agency's priorities.

The results from the process described above were used to develop the final list of projects in the agency's 20-year financial plan. VTA staff are now using the decision-making software, along with updated information on what work is currently being performed, to develop its capital plan for Fiscal Year 2014-2015. Moving forward, VTA expects to continue to develop its asset management data and tools, supplementing its use of the decision-making software for prioritization with additional functionality for projecting future conditions and investment impacts.

Benefits/Outcomes

The major outcome of VTA's asset management efforts is that VTA has been successful in developing a financial plan that recognizes future infrastructure renewal and replacement needs, and that demonstrates a path to funding a major expansion of the VTA system while continuing to operate and renew the infrastructure supporting existing services. Further, VTA expects that the projects it performs based on its improved approach to project prioritization will maximize the use of available funds, and provide results consistent with agency goals and objectives.

Sources and Other Resources

Information provided by a senior contact at VTA.

Outline Key Asset Management Activities and Roles and Responsibilities

The asset management plan described in Section 3, should list the agency's approach to achieving the target it has set for improving asset management. The plan has two major components:

- Enterprise-wide implementation actions that provide enabling support and direction for asset management across all asset classes and services
- Direction and expectations for asset class owners and department managers regarding lifecycle management planning and processes—with a focus on the lifecycle management plans (see Section 3)

The plan outlines how people, processes, and tools come together to address the asset management policy and goals. It should clearly identify the outcome to be achieved (the target), and provide detail regarding how each of the projects that comprise the asset management improvement program will be completed – with a focus on the first year. As with all well managed implementation programs, each of the asset management activities should be broken down into small, manageable, and well-communicated tasks, with agree timelines and resources allocated. Ideally, each project, or activity, has a clear scope, work plan, and work breakdown structure so that the project can be managed successfully. When documenting the activities, it will also be important to document any potential risks and outcomes. This will be important for communicating to stakeholders and managing the overall initiative.

"This is both an operating and capital initiative. Neither area within your agency should dominate. Maintenance-driven or capital-driven programs are not as efficient as combined programs."

– U.S. Transit Agency Manager
(Source: 2011 Parsons Brinckerhoff Survey)

Implement the Asset Management Improvement Program

With a plan in the place, the agency should be ready to implement the asset management improvement program. While implementation will address the activities outlined in the plan, this section describes the approach to developing the strategy around two key asset management enablers: communications and information systems.

Develop a Communications Strategy

Communication is a critical part of change management and is fundamental to any asset management improvement program. No matter the level of asset management maturity or the selected implementation path, no change initiative can be successful without the awareness and buy-in of everyone involved. It is important to identify who your agency's stakeholders are and how they are connected to asset management. In some cases, these stakeholders may have a direct implementation role (for example, a maintenance staff member); however, in other cases, a stakeholder may participate in the goal-setting process and only feel the impacts of improved asset management (for example, interest member group or a rider).

"Our agency learned that the buy-in of internal and external stakeholders is invaluable. Upper management must see the SGR [state of good repair] database as an important tool for asset management, capital program development, and long-term financial planning. At the same time, department managers must see the benefit of inputting accurate and complete data. The process must also be understood by State policymakers and legislators to receive increased funding."

– U.S. Transit Agency Manager (Source: 2011 Parsons Brinckerhoff Survey)

The Asset Management Program Manager should establish a communication strategy that addresses the interests of each stakeholder group. The communication messages, timing, delivery mechanism, and feedback approach should be specified in a communication strategy. On an ongoing basis, the Asset

Management Program Manager and the Asset Management Improvement Team should be communicating the key activities, accomplishments, and challenges associated with the asset management improvement program. It can also include any changes to policies and notifications for any upcoming events. This may occur through email newsletters, updates at department meetings, and flyers posted in visible locations. Additionally, staff should be given the opportunity to participate in the asset management improvement program when possible.

Important considerations when communicating anything related to the asset management improvement program include:

- The message must be created clearly and with sufficient detail, and must convey integrity and commitment.
- The message must be relevant to the recipient's job and it should be clear how asset management could benefit that staff member ("What's in it for me?").
- Staff must be willing to listen, ask questions, and trust the sender.
- The message must be delivered in a format that is accessible and acceptable for staff.

Determine Information Systems Strategy

This section provides added detail on considerations and steps for implementing improvements to asset management information systems. This detail is provided because at its core, asset management applies rigorous, fact-based decision-making using information about the performance of an asset across its lifecycle. This requires an information systems infrastructure that specifies what tools, including functional and technical requirements, will best support the selected implementation path. An agency's existing tools may already address aspects of the asset management strategy's needs, but it is likely that improvement is required to data administration and management practices in addition to software upgrades, integration, and/or development. Added detail is provided because implementing information systems changes in many transit agencies involves considerable risk, can take a long time, is costly, and requires technical competencies that are usually not "core" to a transit agency.

As part of the implementation program, it will be necessary to identify the system solution that most cost-effectively addresses the agency's asset management information requirements. The key steps involved in determining the agency's asset management information systems strategy include:

- Define and document high-level enterprise asset management (enterprise asset management) system requirements.
- Conduct an information technology infrastructure needs assessment.
- Conduct fit/gap analysis on system alternatives.

- Identify and conduct alternatives analysis.
- Select system and implement.

These steps are designed to help an agency identify their asset management system requirements, the best available solution, and the benefits they may expect from the software solution.

A sample set of high level functional requirements is presented below to act as a starting point for agencies:

- Track asset inventory (rail, rolling stock, bus stops, park and rides, etc.).
- Retrieve data easily and update the inventory.
- Record current inventory condition.
- Track warranties on all assets.
- Update inventory condition, and maintain historical condition data.
- Automatically rate assets based on condition and rating thresholds stored in the system.
- Automatically flag infrastructure assets for preservation, betterment, or maintenance based on condition, usage, and depreciation information.
- Provide capability to make asset preservation trade offs based on current conditions, deterioration trends, and available funds.
- Support capital programming and O&M budgeting processes.
- Integrate financial (budget) data, track expenditures on assets.
- Provide the ability to perform online and batch queries (ad hoc reporting) of inventory across the agency.

Define and Document High-Level Enterprise Asset Management Information System Requirements

As discussed in Section 4, an enterprise asset management information system is a tightly integrated system architecture that integrates various systems, including, for example, the maintenance management system, condition monitoring and detection systems, and the financial software, to inventory, exchange and analyze data. It is critical for the agency to define and document high-level requirements to ensure that the key stakeholders are in agreement on the system needs, and the agency has a clear understanding of the functionality expected from the tools. This includes determining the following:

- System functionality (What should the system be able to do?)
- Technical requirements (Where will the data be stored? Should the system be web-based?)
- Level of integration of the systems (Are we tracking the same data in multiple places?)

All of this information should be documented in an information systems requirements document. Typical practice is to prioritize requirements on a 3-point or a 5-point scale. A 3-point scale (High–Business critical; Medium–Important; Low–Desirable) is generally preferred.

Conduct an Information Technology Infrastructure Needs Assessment

With consideration for the enterprise asset management vision, the agency should document how well its current systems address those requirements. This assessment can be conducted through user interviews and a thorough analysis process to determine how well each system and sub-system addresses the requirements outlined in the first step. By understanding the strengths and weaknesses of the existing systems, the agency will be able to evaluate the costs and benefits of implementing a new system. Additionally, understanding the current level of integration between the different systems will allow the agency to evaluate how a new system, if needed, will fit in the agency's information technology architecture or ecosystem.

This step should include a review of the agency's plans for system upgrades. If any plans exist, the agency should determine how the upgrades/changes will affect current systems as well as any new capabilities that may be added. Agencies have also been moving to data warehouses to allow data from disparate systems to be integrated and analyzed together.

Conduct Fit/Gap Analysis on System Alternatives

This step involves comparing the functionality of Commercial-Off-the-Shelf (COTS) software to the agency's requirements. Remember: The key is to first define the asset management business processes (as described in Section 3 of this guide) because the software should be evaluated against its ability to enable these processes. This can include discussions with software vendors and peer agencies using the software alternatives to obtain a perspective on the system capabilities, implementation challenges, as well as lessons learned during prior implementations. The agency may also consider custom-developed software if some or many of the requirements are not able to be met by any COTS.

> When evaluating software alternatives, an agency should consider learning from the industry's experience by conducting a peer (agency) review, (software) industry review, and/or visiting peer agency's sites.

Identify and Conduct Alternatives Analysis

Based on the previous step, the agency should have identified a small number of software alternatives. The alternatives may include COTS solution(s), custom software, and "best of breed" system (COTS along with custom software/add-ins). A benefit/cost analysis of these can include the following for each alternative:

- Degree of fit with agency's strategic direction.
- Degree of fit with business requirements.
- Consistency with agency/stakeholder IT direction.
- Speed of implementation.
- Total cost of ownership – The software estimate should include the cost of developing software, cost to implement (both agency staff as well as vendor costs), hardware costs (computers, servers, additional bandwidth, among others) and regular maintenance costs (for COTS). *Note: The cost to implement, including both staff costs and vendor costs, can be more than the software itself. For example, most states realize that the cost of software license for an ERP solution could be just 1/10th of the total implementation costs.*
- Degree of risk.
- Incremental expandability and flexibility.
- Breakeven point (in years) – Allows the agency to realize how long it will take to recoup the investment. The analysis should also include key risks associated with each alternative.
- Benefits – Includes quantifiable, as well as those than cannot be quantified. As a general rule, benefits should be quantified to the extent possible. These should include both direct benefits (e.g. staff time savings in entering data, data analysis) as well as indirect benefits (e.g. social benefits).

This analysis allows an agency to determine its budgetary needs, timeline, and whether a Request for Proposal (RFP) should be released for a COTS, custom, or a "best of breed" software.

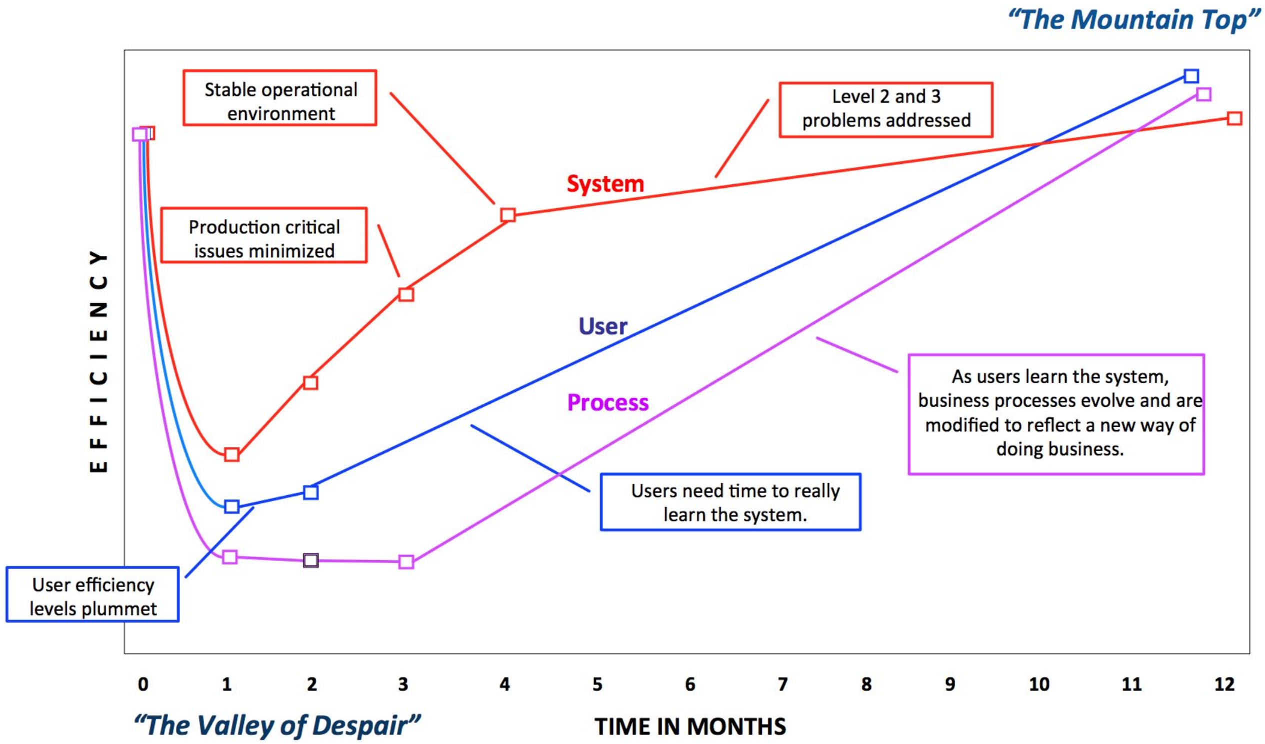
The benefits and shortcomings of both COTS and custom software are provided below:

- COTS software costs are generally lower than custom developed systems and, if done correctly, can have less risk.
- COTS software is generally used by a number of clients, allowing the agency to obtain support from other clients that may include agency's peers.
- Generally, COTS software developers update their software regularly to add new functionalities, providing their users an incentive to upgrade (and pay additional licensing/configuration/support costs in some cases), and also to ensure that their software provides more value to the customers than their competitors. As a result, the user interface and capabilities of current COTS software can be expected to improve over time.
- COTS systems are usually designed with multiple clients in mind, and therefore may not meet all the needs of an agency. At the same time, the system may attempt to incorporate best practices among various agencies (as best deemed by the software vendor, and may include feedback from current and future clients) to make the software more attractive to agencies.
- Any customizations made by an agency may not work and need to be updated if the software vendor releases software updates.
- Developing new software from scratch generally adds additional cost and schedule risk. Implementing a COTS system is generally faster than developing the custom software and implementing it.
- The custom software typically meets an agency's needs more so than COTS software.
- Custom software can be maintained in house, and can be updated to add new functionality more easily than COTS. On the other hand, custom software may require the agency to maintain IT resources in house (if current staff do not have the capacity or capability) thus increasing maintenance costs.
- The custom software can be developed following the agency's IT standards, and is more compatible with other agency software.

Select System and Implement

Once the alternatives analysis is complete and the agency has selected the most feasible alternative, the next step is to release an RFP, review responses, select a vendor, and begin the implementation phase.

Project success is heavily dependent on how the implementation phase is managed. In fact, according to the Standish Group (which collects data on IT project successes and failures), only about 16 percent of projects are truly "successful." The majority of the projects face challenges during the implementation stage. Furthermore, staff efficiency does not increase as soon as a system is implemented. Most systems go through a "stabilization" phase where the staff gets used to the new system interface, usability, and capabilities, during which the efficiency actually decreases before increasing to new levels. Figure 5-8 shows an example of the stabilization period.



Source: Presentation by Louisiana Department of Transportation & Development at 91st Annual Transportation Research Board conference (January 2012)

Figure 5-8 *Example of a System Stabilization*

> *"Our biggest challenge is the disparity in the level of asset management maturity in each department."*
>
> *– U.S. Transit Agency Manager (Source: 2011 Parsons Brinckerhoff Survey)*

Key Implementation Planning Considerations/Lessons Learned

The following list describes implementation considerations and lessons learned based on feedback from transit agency managers and other transportation leaders from around the world:

- As part of an agency's asset management plan update, the Asset Management Improvement Team should capture lessons learned to ensure that the plan is updated to reflect these findings.
- Regularly re-visit asset management goals to ensure that the agency is constantly striving to improve. There is no end to the process; there are always opportunities for further improvement.

- Asset management in the transit industry is constantly evolving as agencies endeavor to improve their existing practices. Seek opportunities for knowledge sharing within the industry. Industry conferences and workgroups may provide good opportunities.
- When possible, involve staff who have worked in different agency departments (e.g., operations and maintenance, engineering, finance). These people likely have relationships and a technical understanding of both departments, which can help to bridge the traditionally siloed areas.
- An agency-wide risk assessment can help the agency to understand the asset classes that the present the highest business risk; this information can then be used to support decision-making.
- Consider the importance of developing transportation leaders to fill future needs. The Asset Program Manager should consider creating a succession program to train and groom future leaders. This could be as easy as informal shadowing opportunities for junior managers or line staff.

Improvement initiatives fail or do not yield their full potential for many reasons, including the absence of a change champion, loss of commitment and motivation, or inadequate executive support. Transformation can also collapse during the execution phase because of unclear strategy and conflicting priorities or an ineffective management team. Tactics for addressing these potential failures include:

- Plan, talk, and act as if implementation is key, right from the start.
- Avoid skirting difficult issues, compliment personal skills, discuss weaknesses, and avoid silence.
- Track and respond to performance indicators to assess, change course, and adjust, but keep in mind that some changes may take time to produce results.
- Ask what activities can be curtailed to free up resources for this change.
- Nurture and empower the right champions and change agents.
- Shepherd good ideas, insights, and connections.

- Areas of lifecycle cost and risk can be challenging to quantify or even capture. Some assets do not decline in functionality, but rather work until failure, at which point it is an extremely lengthy process to rebuild/restore service.
- When planning for an asset management improvement program, acknowledge that the improvements may take a number of years to fully implement. For this reason, it is important to develop long-term strategies while also considering short-term “wins” to maintain momentum. Examples might be centralizing an asset inventory, communicating performance metrics to stakeholders, and developing one asset class’ lifecycle management plan.
- Asset management often involves a significant amount of jargon. Use simple language whenever possible and, when introducing more complex terms, clearly explain their meaning and use them consistently.

- Encourage a hands-on approach from staff. Allowing staff to "get their hands dirty" and actively participate in infrastructure needs assessments and solutions might be the best way to obtain tangible, short-term gains/savings in asset management and set the stage for rolling ideas from lower staff levels to corporate strategic levels.
- Provide direction without being too prescriptive. Staff should be allowed to collaborate, which leads to more innovation.
- Treat asset management as a journey and not a destination. Continuous improvement is fundamental.

"It took us five years to become an overnight success!"

– U.S. Transit Agency Manager (Source: 2011 Parsons Brinckerhoff Survey)

GLOSSARY

This guide introduces concepts that may be new and terms that are not commonly used in many transit agencies today. These can provide the basis for a common voucabulary and understanding. This section provides an explanation of the key concepts mentioned throughout and a common language for the industry.

Key Concepts

Asset Management – Transit asset management is a strategic and systematic process through which an organization procures, operates, maintains, rehabilitates, and replaces transit assets to manage their performance, risks, and costs over their lifecycle to provide safe, cost-effective, reliable service to current and future customers.

Asset Management Business Plan – Refers to a document that outlines the implementing activities, roles, responsibilities, resources, and timelines needed to address an agency's asset management policy and strategy. More information on developing an asset management business plan can be found in Sections 3 and 5.

Asset Management Maturity – Refers to an agency's level of asset management practice. An agency's asset management maturity may be as basic as understanding what assets it owns; however, a more mature asset management agency will be able to use that asset information to model different funding scenarios and optimally allocate funding to its assets. More information regarding asset management maturity levels is found in Section 5.

Level of Service – Level of service is the defined service quality that the agency and its assets are expected to deliver and be measured against. Levels of service usually relate to the quality, quantity, reliability, responsiveness, sustainability, cost, and cost efficiency of service. It applies at the enterprise level and for asset classes (for example, buses and elevators). Generally, level of service should be driven by what is important to the customer.

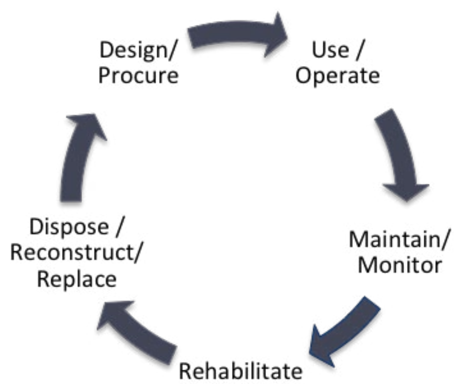
Lifecycle Cost Analysis – Lifecycle Cost Analysis (often abbreviated LCCA) is an approach for measuring an asset's total cost of ownership, usually to facilitate a financial comparison of investment options. It includes the estimation of both capital and operating costs of an asset at each lifecycle stage or activity (see Lifecycle Management). Estimated costs are typically in current dollars (versus escalated) terms to allow direct comparison. Costs may also be normalized to a particular time horizon to account for varying design lives.

Lifecycle Management – Lifecycle management enables agencies to make better investment decisions across the lifecycle using management processes and data specific to each asset as a basis for predicting remaining useful life (including age, condition, historic performance, and level of usage). Transit asset management involves processes for managing and maximizing the performance of an asset while minimizing its costs throughout the course of its lifecycle. Lifecycle activities include the following (see figure):

- **Design/Procure** – If creating, this includes planning, design, and construction of the asset. If acquiring, this includes the scoping of the development and procurement of the asset. The asset management perspective involves considering level of service requirements and total cost of ownership in this initial step.
- **Use/Operate** – This involves the use (or operation) of the asset. Asset management ensures that the asset is available in the specified condition to be used, or operates reliably to deliver the planned level of service.
- **Maintain/Monitor** – This involves all the predictive, preventive, corrective, and reactive activities required to maintain the asset in the condition required to deliver the planned level of service.
- **Rehabilitate** – Rehabilitation is the planned capital expenditures required to replace, refurbish, or reconstruct an asset partially, in-kind, or with an upgrade to optimize service and minimize lifecycle costs. Examples might include reconstruction work on a bridge structure that replaces critical elements and thereby extends the bridge's life or a rail vehicle overhaul.
- **Dispose/Reconstruct/Replace** – When an asset can no longer perform at its intended level of service, the agency has the choice to dispose, reconstruct, or replace the asset. Typically at this stage, it is no longer cost effective to renew the asset or it is functionally obsolete, and the agency must determine whether the asset must be replaced, whether the function of the asset remains necessary, and whether its function can be met more economically or efficiently by being replaced outright.

Lifecycle Management Plan – Documents the costs, performance, and risks associated with an asset class throughout its life. Reflecting input from all departments that are involved in that asset's lifecycle, a lifecycle management plan can be used to ensure that the performance expectations of the asset are understood and fit within the agency's broader goals and performance objectives, and that all investment decisions are transparent and well-communicated. More information regarding developing a lifecycle management plan can be found in Section 3.

Asset Lifecycle Activities



Other Terminology

Asset Category – Refers to a grouping of asset classes. For example, "Vehicles" is the asset category for two asset classes: "Rail Vehicles and Fixed Guideway Non-Revenue Vehicles" and "Buses, Paratransit and Non-Revenue Vehicles." More descriptions on asset categories can be found in the Asset Management Guide Supplement.

Asset Class– Refers to the sub-groups within an asset category. For example, "Vehicles" is the asset category for two asset classes: "Rail Vehicles and Fixed Guideway Non-Revenue Vehicles" and "Buses, Paratransit and Non-Revenue Vehicles." More descriptions on asset classes can be found in Asset Management Guide Supplement.

Asset Class-Level – Refers to any management or decision-making activities that occur for individual asset classes. For example, the condition monitoring approach for stations is an asset class-level business process, while establishing an agency-wide policy is an enterprise-level business process.

Asset Management Business Processes – Refers to the six key processes that comprise the transit asset management framework. Business processes include, for example, asset management policy, capital planning and programming, and condition assessment and performance monitoring. For each business process, Section 3 describes what best practice looks like, key implementation activities and challenges, and peer examples.

Asset Management Framework – The asset management framework provides a structure that outlines best practice in asset management practice. It is comprised of six business processes, including, for example, asset management policy, capital planning and programming, and condition assessment and performance monitoring. An introduction to the framework is found in Section 2 and overview of each of the framework business processes is found in Section 3.

Asset Management Program Manager – Refers to the person held accountable for developing, maintenance, and implementation of the asset management business plan. Additionally, this person is responsible for communicating with the Executive Team, leading the Enterprise Asset Management Team, and managing internal and external communications regarding the asset management initiative. More information regarding the role of the asset management program manager is found in Section 5.

Asset Owners – Refers to the agency staff or department responsible for managing the full lifecycle of an asset class. These are typically the same group responsible for developing and maintaining that asset class' lifecycle management plan. More information regarding the role of an asset owner is found in Section 5.

Enterprise Asset Management Team – Comprising representatives from maintenance, operations, engineering, capital planning, information technology, and other related departments, this group provides the asset management knowledge and practice leadership for the agency. This cross-functional team represents their department's technical expertise and interests. This group's role is to be the owners of improved processes or have the changes incorporated in the work of their units. More information regarding the role of the enterprise asset management team is found in Section 5.

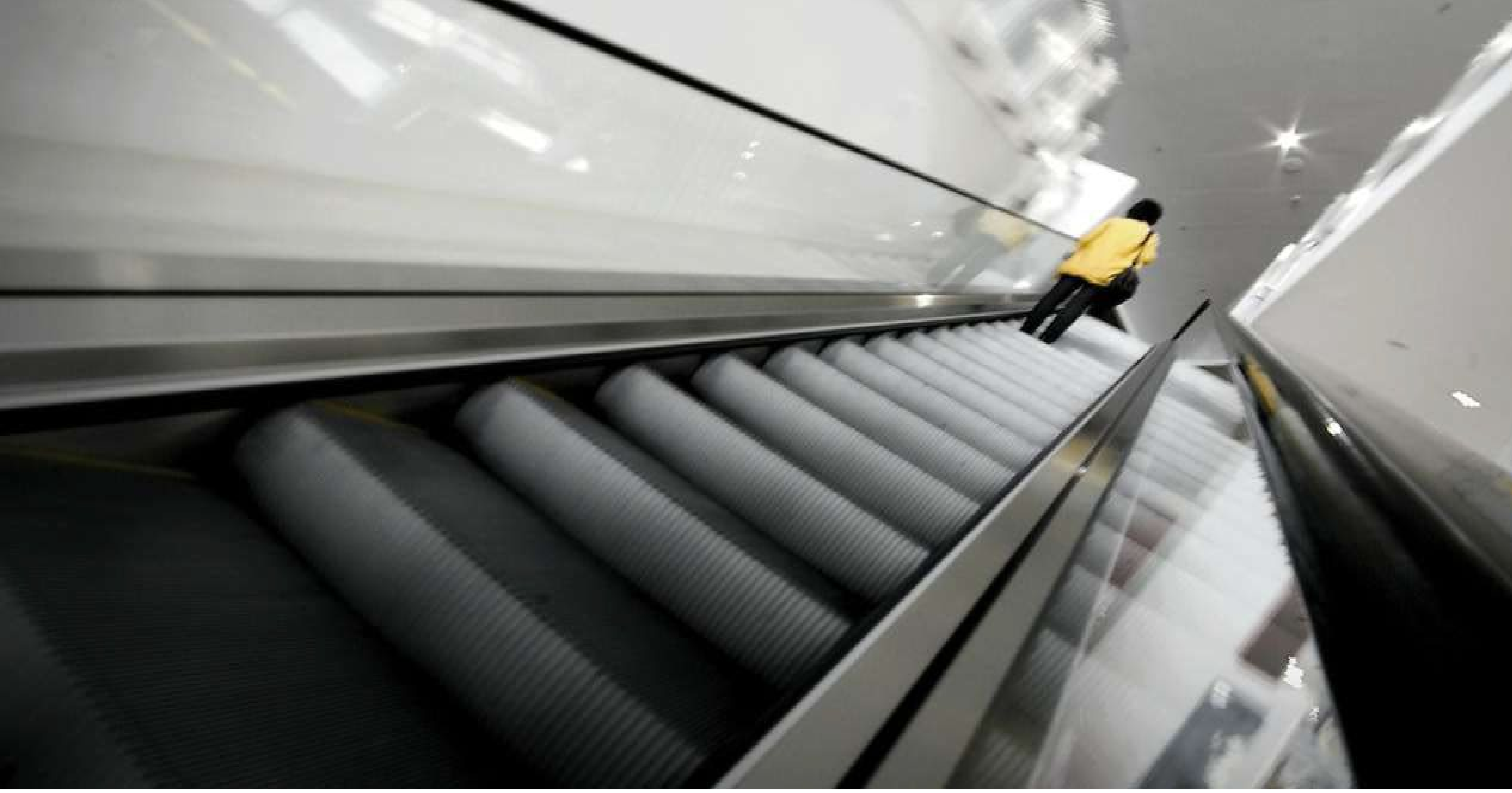
Enterprise-Level – Enterprise level activities refer to any management or decision-making activities that need to occur at the higher levels of an organization and apply to the entire organization. Transit asset management integrates activities across functions in a transit agency to optimize resource allocation by providing quality information and well-defined business objectives to support decision-making within and between classes of assets.

Performance and Predictive Modeling – Transit asset management involves establishing models to predict the performance of an asset and asset condition over time based on its use, natural processes, and maintenance, operating, and rehabilitation practices. Modeling techniques and the nature of assumptions vary by asset class. Performance and predictive modeling can assist in the identification of underperforming assets and provide useful information to improve capital programming and O&M budgeting decisions. More information about performance and predictive modeling can be found in Section 3.

Performance Management – The American Association of State Highway and Transportation Officials (AASHTO) defines performance management as an ongoing process that translates strategic goals into relevant and detailed measures and targets that, along with resources, are continuously monitored to ensure achievement of published institutional goals. Asset management is a management process that directly impacts critical business metrics of cost, reliability and safety. It explicitly links strategies, plans, operations, and budgets to level of service. Advanced transit asset management practices involve scenario evaluation that incorporates service levels, asset lifecycle needs, and performance based on varying funding levels.

Risk Management – Risk management is the process through which risks are identified, assessed and managed. Risk management approaches can range from completely ad-hoc to very formal, yet they all share the same fundamentals. Most importantly, the primary objective for any of these risk management approaches is to improve the performance of the agency as a whole and individual business areas. Each approach seeks to anticipate risks and opportunities and then develop management strategies to minimize the occurrence of negative events. More information about risk management can be found in Section 2.

Total Cost of Ownership – Reflects the total estimated capital and Operations and Maintenance costs associated with an asset throughout the its lifecycle (including the cost to design/procure, use/operate, maintain/monitor, rehabilitate, and dispose/reconstruct/replace. The total cost of ownership should be represented in an asset's lifecycle management plan.



Source: Steve Kay

REFERENCES

AECOM. *Project No. NCHRP 0869 Supplement to the AASHTO Transportation Asset Management Guide: Volume 2 - A Focus on Implementation*. Arlington, 2010.

Bridges, Michael. *Transportation Asset Management: A Framework for Successful Performance-Based Planning*. Presentation. 2010.

Cambridge Systems, Inc., Parsons Brinckerhoff Quade & Douglas, Inc., Roy Jorgenson Associates, Inc. and Paul D. Thompson. *Transportation Asset Management Guide November 2002*. NCHRP Program 20-24 (11). 2002.

Canadian National Railway Company. *Canadian National Railway Company: Enabling A Service-Led Railway with SAP ERP*. 2010.

CIRIA. *Whole-life Infrastructure Asset Management: Good Practice Guide for Civil Infrastructure*. London, 2009.

Davis, Jonathan R. *Massachusetts Bay Transportation Authority: State of Good Repair Initiative*.

Presentation. 2008. Federal Transit Administration State of Good Repair Database. Federal Transit Administration. *National State of Good Repair Assessment*. 2010.

Ferragut, Ted, and Sue McNeil. *Transportation Asset Management: Strategic Workshop for Department of Transportation Executives*. 2008. Transportation Research Circular.

Gordon, Mark, George Jason Smith, Paul D. Thompson, Hyun-A Park, and Brett Elston. *Supplement to the AASHTO Transportation Asset Management Guide: Volume 2 - A Focus on Implementation*. NCHRP 08-69. Natchez, Mississippi, 2010.

Institute of Asset Management. *Asset Management Landscape*. Draft A. 2011.

James, Aaron C. *Addressing the Challenge: Formulating a Definition of SGR for a Federal Program*. Presentation. 2010. Federal Transit Administration Second State of Good Repair Roundtable.

Kirwan, Andy, and Teodor Gradinariu, eds. *Guidelines for the Application of Asset Management in Railway Infrastructure Organisations*. Paris: International Union of Railways (UIC), 2010.

LBT. *International Transit Studies: Tools & Systems*. Presentation. 2010. Federal Transit Administration State of Good Repair Roundtable.

Lloyd, Chris, and Charles Johnson. *Becoming an Asset Management Organisation. Assets: The Magazine for Members of the Institute of Asset Management,* Aug. 2010: 16-18.

Mincom. *A PAS 55 Approach to Asset Management*. White Paper. 2010.

Roberts, Dr. Christian. The Transit Paradox. *Assets: The Magazine for Members of the Institute of Asset Management* Feb. 2010: 24-26.

Rutledge, Jerry. *TCRP International Studies: State of Good Repair Study Mission, Focus Topic - Definition and Measurement*. Presentation. 2010. Federal Transportation Administration Second State of Good Repair Roundtable.

Schneck, Donald C. Task Summary Status Report for the Useful Life of Buses and Vans Study. Letter to Henry Nejako. 15 Nov. 2006.

Transportation Research Board, Metropolitan Transportation Authority. *The View from the Subway (Bus, Railroad, Bridge & Tunnel): The Challenges of Maintaining and Operating a 100(+) Year Old System*. Presentation. New York, 2009.

U.S. Department of Transportation Federal Highway Administration Office of Asset Management. *Asset Management Primer.* U.S. Department of Transportation, 1999.

U.S. Department of Transportation Federal Highway Administration Office of Asset Management. *Life Cycle Cost Analysis Primer.* 2002.

U.S. Department of Transportation Federal Highway Administration. *NHI Course 131112: Maintenance Management Systems*. Lessons 2-7.

U.S. Department of Transportation Federal Transit Administration. *Current Conditions of the Nation's Transit Infrastructure: FTA State of Good Repair Workshop.*

U.S. Department of Transportation Federal Transit Administration. *Rail Modernization Study: Report to Congress*. Washington DC, 2009.

U.S. Department of Transportation Federal Transit Administration. *Transit Economic Requirements Model: Overview and Application*. Presentation. 2009.

U.S. Department of Transportation Federal Transit Administration. *Transit Asset Management Practices: A National and International Review.* Rep. 2010.

U.S. Department of Transportation Federal Transit Administration. *Transit State of Good Repair: Beginning the Dialogue*. 2008.

U.S. Department of Transportation Federal Transit Administration. *Transit Asset Management: FTA State of Good Repair Workshop*.

U.S. Department of Transportation Federal Highway Administration. *Transportation Asset Management In Australia, Canada, England, and New Zealand*. 2005. International Technology Exchange Program.

U.S. Department of Transportation Federal Transit Administration. *Useful Life of Transit Buses and Vans*. Project VA-26-7229. 2007.

APPENDIX

A

Asset Management Guide Supplement

U.S. Department of Transportation
Federal Transit Administration

Asset Management Guide **Supplement**

Asset Class Overviews & Lifecycle Management

Prepared for

Department of Transportation
Federal Transit Administration
1200 New Jersey Avenue, SE
Washington, DC 20590

Prepared by

Parsons Brinckerhoff, Inc.
One Penn Plaza
New York, NY 11019

Principal Authors

Dr. David Rose, Parsons Brinckerhff
Lauren Isaac, Parsons Brinckerhoff
Tagan Blake, Parsons Brinckerhoff

Table of Contents

Tables

Figures

Glossary of Terms

AASHTO	American Association of State Highway and Transportation Officials
AC	Alternating Current
ADA	American with Disabilities Act
ANSI	American National Standards Institute
APTA	American Public Transportation Association
AREMA	American Railway Engineering & Maintenance-of-Way Association
ASCE	American Society of Civil Engineers
ASHARE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASHRAE	American Society of Heating Refrigerating and Air Conditioning Engineers
ASPE	American Society of Plumbing Engineers
ASTM	American Society for Testing and Materials
ATC	Automatic Train Control
BEES	Building for Environmental and Economic Sustainability
BOMA	Building Owners and Managers Association
BRT	Bus rapid transit
CBTC	Communications-based train control
CCTV	Closed circuit video
DBFOM	Design-Build-Finance-Operate-Maintain
DBOM	Design-Build-Operate-Maintain
DMU	Diesel-electric multiple units
DOT	Department of Transportation
EMS	Environmental management system
EPA	Environmental Protection Agency
EPM	Electrical Preventive Maintenance
FCC	Federal Communications Commission
FHWA	Federla Highway Adminsitration
FRA	Federal Railroad Administration
GPS	Global positioning systems
HVAC	Heating, Ventilation and Air Conditioning
ICS	Industrial Control Systems
IDIQ	Indefinite Delivery and Indefinite Quantity
IEEE	Institute of Electrical and Electronics Engineers
IFMA	International Facility Management Association
LEED	Leadership in Energy and Environmental Design
MTA	Metropolitan Transportation Authority
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
NEMA	National Electrical Manufactures Association
NETA	International Electrical Testing Association
NFPA	National Fire Protection Association
OCS	Overhead Catenary System
RAMS	Reliability, Accessibility, Maintainability and Safety
RCRA	Resource Conservation and Recovery Act
RFP	Request for Proposal
SCADA	Supervisory control and data acquisition
SI	Spark-ignitions
SIS	Strategic Intermodal System
SMACNA	Sheet Metal and Air Conditioning Contractors’ National Association
SWPP	Storm Water Pollution Prevention Plan
TCRP	Transit cooperative research Program
TSA	Transportation Security Administration
UFC	Unified Facilities Criteria
UPS	Uninterrupted power supply
USDOT	United States Department of Transportation
VMS	Variable message sign
VOC	Volatile organic compounds

Chapter 1

Introduction

This supplement presents additional information to readers of the Federal Transit Administration's *Asset Management Guide*. While the *Asset Management Guide* addresses asset management business processes, this supplement provides insight into how those processes can be applied to each major asset class. The supplement highlights what it means to be an asset manager and provides examples of techniques and approaches used in good asset management practice, as well as references to existing standards.

A central element of successful enterprise asset management is having a lifecycle management process and plan in place for each major asset class and, as applicable, for individual assets. The typical elements of this process are described in Section 3.2.3 of the *Asset Management Guide*.

This supplement provides information and guidance on the building blocks of lifecycle management for each asset class. While Chapter 3 of the *Asset Management Guide* identifies the process and components of a lifecycle management plan, this supplement describes the methods and considerations for managing across the whole lifecycle for each major asset class. This information is intended to support the development of an agency's asset class–specific lifecycle management plans.

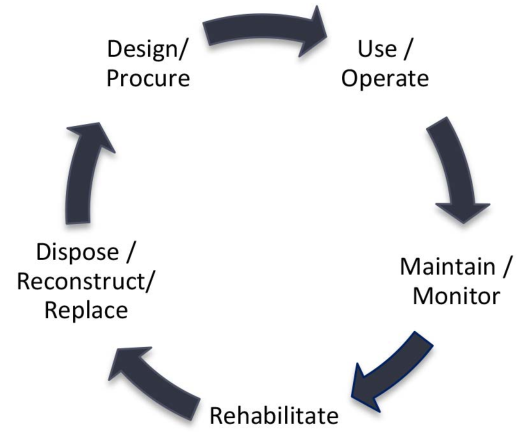
The audience for this supplement is both the respective manager (or owner) for each asset class and others who require broader understanding of contemporary practices and issues involved in the lifecycle management of the various asset classes.

There is a wide range in the maturity of asset management practice across the asset classes. In the United States, for many asset classes there are no harmonized or authoritative standards of best practice for asset inventories, condition assessment, or performance modeling in the transit industry. This supplement provides a general characterization of approaches for managing across each asset class's lifecycle, giving specific examples where possible. The supplement also provides an overview of sources for existing industry standards.

1.1 Lifecycle Management Principles

Lifecycle management planning is intended to drive successful service delivery and financial performance by minimizing the cost to procure, operate, maintain, rehabilitate, dispose of, and replace (see **Figure 1-1**) an asset while meeting or exceeding established service and reliability commitments for both the asset and the transit system as a whole. Building on Section 3.2.3 of the *Asset Management Guide*, a mature approach to lifecycle management planning encompasses the following principles:

Figure 1-1. Asset Lifecycle Steps



- Establish an **organizational foundation**
  - Ensure all functional departments have the necessary resources—including staff, equipment, and technology systems—to effectively carry out performance monitoring and improvement.
  - Define roles and responsibilities of staff—including "asset owners"—to ensure accountability for performance.
  - Encourage collaboration among various asset management partners to better share information and identify and address issues.
  - Address asset interrelationships and their organizational, operational, and performance implications.
- Emphasize a **data-driven approach**
  - Map asset management activities to an asset inventory.
  - Use management control systems and high-quality business processes to collect and maintain valuable data.
  - Periodically inspect assets to measure their condition in order to optimize maintenance and investment and evaluate the timing and effectiveness of asset management activities.
  - Ensure sufficient data are collected to evaluate performance against established targets and to identify and prioritize issues impacting system performance.
  - Model use, condition, and performance to measure and improve reliability, support improved decision making, and effectively allocate resources.
- Implement **high-quality business processes**
  - Develop a systematic approach to the initial design and procurement of assets, including a lifecycle management plan.

- Establish formal performance improvement processes to ensure identification and diagnosis of performance issues and development, testing, implementation, and tracking of proposed improvement measures.
- Manage performance improvement based on the historical identification and documentation of issues, the development of proposed improvement measures, and the effective implementation of the most cost-effective improvement measures.
- Use a systems engineering approach to optimize asset management practices in complex environments.
- Put in place quality assurance and quality control (QA/QC) measures to sustain asset management activities throughout the asset lifecycle and ensure adherence to the standards, expectations, and assumptions of the transit agency.
- Develop comprehensive risk analysis and risk management measures to support system safety and stability, decision-making, performance improvement, and prioritization of resources.
- Identify and maintain key documentation of asset management practices in response to factors such as a changing operating environment, new guidance from the manufacturer, and new technologies.

Asset owners are responsible for the planning and implementation of lifecycle management. An asset owner is a transit agency manager who is usually in charge of an asset class's maintenance and, ideally, is also involved in asset design and procurement. The asset owner is responsible for lifecycle management planning, for developing and implementing the lifecycle management plan, and for facilitating asset management activities as outlined in **Table 1-1**. The principles listed previously provide a foundation asset owners can use to increase the effectiveness of these lifecycle management activities and thereby drive improved lifecycle management and optimize asset performance.

Table 1-1. Typical Activities to Integrate into Lifecycle Management

Design / Procurement
▪ Project planning ▪ Specification development or design phase ▪ Competitive procurement ▪ Proposal review and selection ▪ QA/QC, testing, and acceptance
Use / Operation
▪ Operator training ▪ Performance monitoring, review, and audits ▪ Contractor / vendor oversight
Maintenance / Monitoring
▪ Maintenance training ▪ Maintenance management system update ▪ Scheduled maintenance and inspections per manufacturer's guidelines, industry standards, and/or applicable regulations ▪ Predictive maintenance based on performance monitoring ▪ Reactive maintenance ▪ Performance monitoring, audits, and QA/QC of maintenance ▪ Advanced diagnostics and performance improvement ▪ Inventory and warehouse monitoring ▪ Contractor / vendor oversight
Rehabilitation
▪ Midlife overhaul, refurbishment, or renovation ▪ Testing and inspection of rehabilitation ▪ Contractor / vendor oversight
Disposal / Replacement
▪ Responsible disposal ▪ Adaptive reuse

1.2 Scope of Lifecycle Management Plans

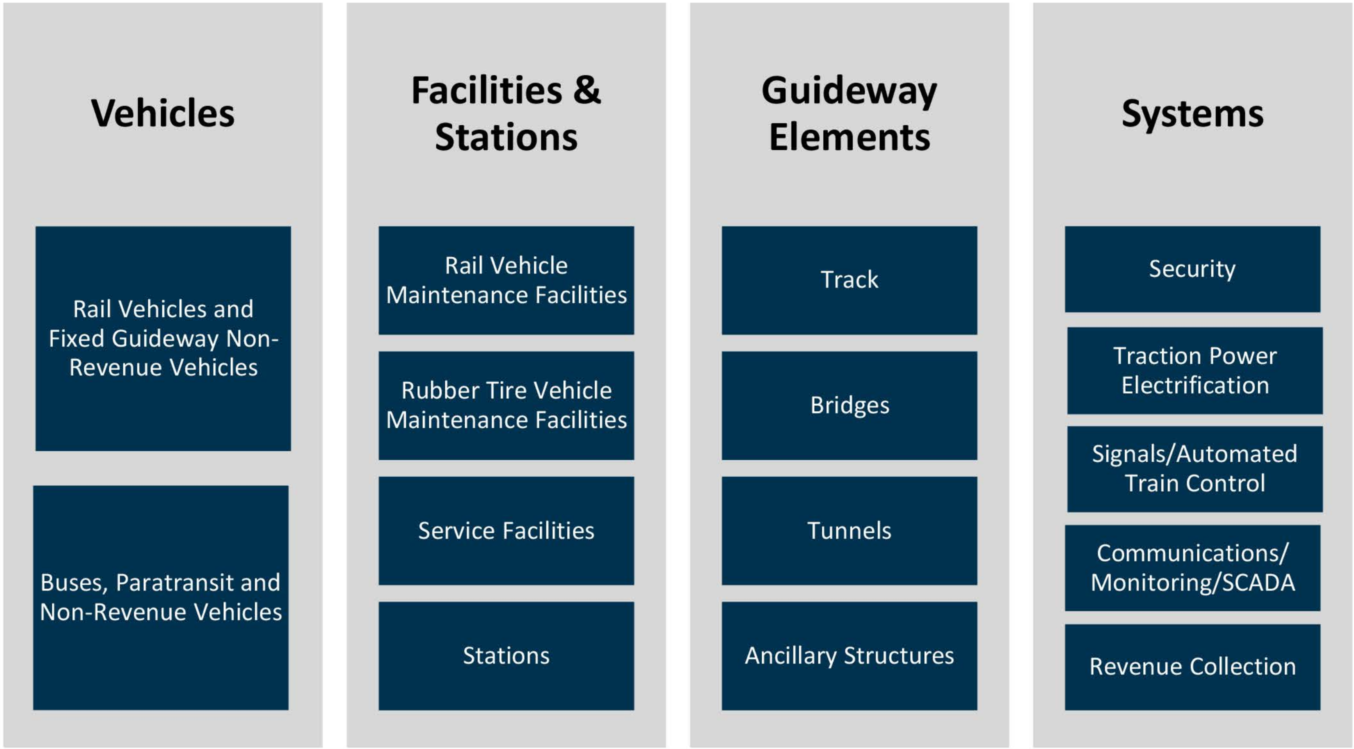
The appropriate level of detail in a lifecycle management plan may vary. The lifecycle management plan can be an effective way to provide managers with a comprehensive, concise, and up-to-date summary document or to provide practitioners with thorough documentation of planning and procedures. For example, a facilities management plan—which is one example of a lifecycle management plan—may thoroughly document preventive maintenance requirements and inspection procedures for all building elements and systems but provide only limited guidance for regular measurement and monitoring of building operational performance. As another example, a fleet management plan can serve as a lifecycle management plan for revenue vehicles, but in practice, fleet management plans tend to be high-level documents focused on the timeline for major capital investments and are often missing many of the foundational lifecycle management planning elements detailed previously. A lifecycle management plan should address each of the asset lifecycle activities in **Figure 1-1** and a mature plan should promote all of the principles laid out previously. However, a lifecycle management plan (such as a fleet management plan) can be high level and still comprehensively address the various aspects of lifecycle management planning detailed previously and in Section 3.2.3 of the *Asset Management Guide*, for instance by referencing specific technical documentation such as the vehicle maintenance manual.

1.3 Asset Categories and Classes

An agency's asset inventory provides the basis for the organization's asset management business planning, data collection, and performance reporting. A hierarchy provides the organization for the asset inventory. The proposed hierarchy presented in **Figure 1-2** is closely aligned to various existing industry asset-class structures. Facilities and stations are combined into a single asset category to reflect their many shared management practices.

An agency's asset management plan should address all major asset classes that it owns. However, this supplement provides guidance on transit-specific assets. Each of the four asset categories is addressed in a subsection of this supplement: Chapter 2 – Vehicles, Chapter 3 – Facilities and Stations, Chapter 4 – Guideway Elements, and Chapter 5 – Systems. Chapter 6 – Sustainability and Asset Management addresses asset lifecycle management from the perspective of sustainability. This supplement does not address roadway, park-and-rides, and administrative or other buildings whose lifecycle management requirements are not unique to the transit industry. This supplement also does not include ferries and other maritime assets. Nevertheless, most of the principles and approaches to lifecycle management planning and implementation outlined in this supplement still apply to these assets.

Figure 1-2. Transit Asset Categories and Classes



Chapter 2

Vehicles

2.1 Asset Class Overview

Vehicles refer to rolling stock that is used to provide revenue or non-revenue service. Rolling stock can include heavy rail, light rail, streetcars, buses, paratransit vehicles, service vehicles, yard tugs, and street supervisor vehicles. Revenue vehicles are among an agency's most critical assets because they deliver an agency's intended service and directly interface with an agency's customers. Revenue vehicles must provide a safe, comfortable environment for passengers and meet the agency's operational requirements regarding factors such as capacity, speed, acceleration, and braking and loading time. Revenue vehicles, including bus and paratransit vans, often include sophisticated equipment for communications, accessibility, safety, and other functions. Each subsystem may have specific asset characteristics that require a distinct management approach. Non-revenue vehicles typically meet narrower requirements relative to revenue vehicles. The asset classes include the following:

- **Rail Vehicles and Fixed-Guideway Non-Revenue Vehicles** refer to any fixed-guideway vehicle supporting revenue or non-revenue service. Revenue rail vehicles include passenger intercity and regional rail, heavy rail/subway, light rail, streetcar and heritage trolleys, automated people movers, and other fixed-guideway vehicles. Non-revenue rail vehicles include track service equipment, tampers, rail grinders, work cars/trucks, hi-rail vehicles, snow removal equipment, and re-railing equipment.
- **Buses, Paratransit and Non-Revenue Vehicles** refers to any rubber-tired vehicle supporting revenue or non-revenue service. Bus vehicles include transit (inner-city), suburban (over-the-road coaches), and specialty vehicles (for example, trolleys and vans). Additionally, dedicated guideway vehicles include bus rapid transit (BRT) vehicles. Non-revenue vehicles include service vehicles, street supervisor vehicles, management vehicles, wreckers, and yard tugs.

Revenue vehicles tend to have maintenance priority among all transit assets, not only because of their critical role, but also because they must meet regulatory requirements and acceptable safety and reliability levels to provide passenger service. Manufacturers provide guidelines for preventive maintenance and replacement, which agencies tend to follow, and maintenance practices are broadly shared across the industry. However, with effective data collection and maintenance planning, vehicle maintenance departments can better allocate scarce maintenance resources to optimize their programs' effectiveness. Similar to other asset classes, lower levels of preventive maintenance can increase long-term costs through deterioration of reliability and abbreviated useful lives or the need for additional costly rehabilitations. Managing maintenance with a multi-year time horizon can improve the reliability of components and systems on the vehicles and result in improved vehicle availability and fewer disruptions to revenue service. Good asset management practices are intended to optimize transit system performance within budget constraints. Conversely, poor asset management practices, such as deferred maintenance, lead to higher costs over the long run and can negatively affect operational performance, exacerbating budgetary issues.

In the case of non-revenue vehicles, transit agencies are less likely to employ mature asset management practices. Non-revenue vehicles are often operated until they fail (unless maintenance is outsourced) and maintenance is unplanned (that is, reactive or unscheduled). Non-revenue vehicles include common sedans or trucks that can easily be leased, or they can be specialized vehicles with built-on equipment that may require special understanding to maintain. In the former case, vehicle leases obviate the need for maintenance. In the latter case, transit agencies may face challenges in allocating resources to properly maintain such vehicles.

Historically, all vehicles were owned by the transit agency, but today, transit agencies use a variety of other approaches. Revenue vehicles may be owned outright and maintained in-house, or the vehicles may be leased and maintained by a third party, usually under a performance-based contract. Similarly, non-revenue vehicles can be owned or leased by the agency and the maintenance may or may not be outsourced. Provided the agency is in a position to go forward with such a procurement and there is a sufficient number of qualified contractors to bid, such alternative operation models can transfer the management of and lifecycle financial risk to vendors and contractors. This can take advantage of contractors' core competencies, expertise, standardized approaches, and economies of scale.

Typical asset classes included in the vehicles category are organized in a proposed asset hierarchy in **Table 2-1**.

Table 2-1. Vehicles Asset Classes' Proposed Asset Hierarchy

Asset Class	Sub Assets	Related Assets
Revenue Rail Vehicles (Primary)	▪ Locomotives and coaches ▪ Electric/Diesel Multiple Unit (EMU / DMU) vehicles ▪ Rapid rail / subway vehicles ▪ Light rail vehicles / Streetcars ▪ Non-rail, fixed-guideway vehicles	▪ Trucks ▪ Wheel and axle sets ▪ Powerplants and propulsion systems ▪ Braking systems ▪ Heating, ventilation and air conditioning (HVAC) systems ▪ Auxiliary power supplies ▪ Transmissions/gearboxes
Revenue Bus Vehicles (Primary)	▪ Passenger buses ▪ Shuttle buses ▪ Paratransit vans	▪ Wheel and axle sets ▪ Powerplants and propulsion systems ▪ Braking systems ▪ HVAC systems ▪ Auxiliary power supplies ▪ Transmissions/gearboxes
Non-Revenue Rail Vehicles (Support)	▪ Track service equipment ▪ Cranes and re-railing equipment ▪ Hi-rail vehicles	▪ Specialized equipment such as tampers, rail grinders, and generators ▪ General propulsion and system equipment ▪ Onboard equipment such as cranes, generators, compressors, and monitoring and diagnostic systems
Other Non-Revenue Vehicles (Support)	▪ Snow removal equipment ▪ Heavy service trucks ▪ Light trucks ▪ Tow vehicles ▪ Forklifts	▪ Onboard equipment such as cranes, generators, compressors, and monitoring and diagnostic systems

2.2 Lifecycle Management Practices

Revenue vehicles follow a predictable lifecycle. Since vehicle procurements are a major agency cost and usually leverage federal grants, transit agencies typically program vehicle purchases years in advance. The agency will develop a comprehensive specification for the procurement that can vary in detail and specificity depending on the size of the agency and the vehicle purchase as well as the agency's specific needs for the vehicles. Purchases of bus and rail revenue vehicles typically include large quantities relative to the overall transit agency fleet size. Once vehicles are delivered, they are maintained by the transit agency or a third party in geographically based maintenance facilities, where various shops and equipment cover most or all of a vehicle's maintenance needs. Transit agencies usually track revenue vehicle performance closely, managing their spare fleet and programming major rehabilitations and replacements. Vehicle useful lives vary from 5 years for some paratransit and non-revenue fleet vehicles to more than 30 years for many rail vehicles. Many vehicle systems and components, such as tires or powerplants, need more frequent replacement.

Vehicle floor panels typically made of plywood usually need to be replaced at midlife because of the wood delamination from moisture absorption. This replacement requires the entire floor of the vehicle to be stripped, removing all interior and undercarriage items that interface with the floor (for example, seats, heaters, sandboxes, stanchions, and lockers). Changing to composite floor panels that last the life of the vehicle eliminates this refurbishment activity, and its cost could be warranted from a lifecycle point of view.

For a number of reasons, vehicle asset management, especially for buses, is more advanced relative to other asset classes. The high level of standardization of vehicles both within and across agencies, the well-developed understanding of vehicle maintenance needs, and the existence of federal and state regulations related to vehicle maintenance mean that most transit agencies have a well-developed understanding of their vehicle asset management needs, including an asset inventory, a fleet plan for capital investments, maintenance guidelines and manuals, and clear business processes for both scheduled and unscheduled inspections and maintenance. Vehicles typically have well-defined lifecycles, operating costs, and acceptable performance standards for operation.

Nevertheless, fleet management can be relatively complex—agencies can choose among diverse power plants for vehicles and must maintain more complex technology systems included on vehicles. As a result, there may exist many opportunities for continual improvement of asset management. For instance, new generations of fleet and maintenance management systems continue offering new capabilities to improve data collection. Vehicles increasingly collect more detailed operating information and diagnostics information, which in some cases can be relayed to maintenance departments in real time. If agencies have the processes and resources in place to effectively integrate and analyze the growing flow of data, they can better identify opportunities for efficiency and cost savings and better manage and respond to the increasing complexity of vehicle assets.

2.2.1 Vehicles (All)

Vehicle asset management focuses primarily on vehicle procurement, the structuring of the vehicle maintenance program, the identification of and response to specific maintenance issues, the planning of system and component replacements, and the management of the spare fleet and inventory. The following sections discuss key considerations from the perspective of the lifecycle management principles detailed in this supplement's Chapter 1 – Introduction. Practical examples illustrate the application of lifecycle management principles across the whole asset lifecycle including the design, preventive maintenance, and rehabilitation and replacement phases.

Design and Procurement Considerations

Performance modeling can play an important role in assessing lifecycle cost implications of design choices. The lifecycle of vehicles can be extended by refurbishing, for example, the engines, floors, seats, axles, and brakes around the midlife point. However, the use of improved modern materials with superior physical properties can provide a much longer service life for these and other vehicle elements. A vehicle design based on improved modern materials and modular assemblies does not necessarily require the traditional midlife overhaul program. In many cases, the manufacturer can be incentivized to undertake such considerations; after all, a higher initial vehicle cost allows the transit agency to capture revenues that would otherwise be used for maintenance and rehabilitation. For instance, if materials resistant to known failure modes (corrosion, decomposition, vibration, and vandalism) are used, many of the common midlife overhaul requirementscan be reduced, postponed, or even eliminated, and then supplemented or substituted with a component-level targeted overhaul. As an example, transit agencies have, in recent years, used composite flooring instead of wood-based materials and stainless steel instead of plastic seats, which usually negates the need for traditional midlife overhauls in these particular areas. Both basic and advanced performance modeling and decision analyses can help to select appropriate materials and systems to minimize the total lifecycle costs, including procurement, operation and maintenance, rehabilitation, and replacement and disposal.

Decision analysis and prioritization are important tools to optimize use of resources and support transparent decision making in procurements. As manufacturers and vendors offer more options for ancillary systems that improve, for example, data collection or passenger comfort, agencies must be sure these systems generate sufficient value and are worth the additional maintenance effort. Transit agencies should guard against adding technology that does not provide a tangible benefit for the passenger, the maintainers, or the transit system. New systems can generate requirements for additional staff, training, risks of part obsolescence or unreliability, and potential additional maintenance. In many cases, it is possible to look to peers to understand the system's record of reliability and cost, but further analysis can help transit agencies understand the tradeoffs inherent in design decisions. A formal prioritization process for vehicle features can be a useful way to assess the tradeoffs in vehicle procurement and can be an opportunity to include important stakeholders (like customers and vehicle operators).

Design review is an important quality control measure that can help improve a vehicle's maintainability and reduce total lifecycle cost. Design review may include use of a third-party consultant or peer or a special design-review committee composed of cross-functional experts from within the agency.

> A review of maintainability would involve experienced maintenance staff and require their comments and sign-off on the specification. As an example of the potential benefits, maintenance staff may be able to identify a maintenance task that is difficult to perform for ergonomic reasons may result in increased setup time, may require additional protective equipment, or may result in injuries to personnel. An example of this is the idea of using four automotive type batteries in lieu of the traditional single (8D type) battery, which is heavy and cumbersome to remove and replace. Including design team members either from the agency, supporting consultants, or manufacturers and contractors with substantial maintenance experience to identify these issues early in a project is one measure to address vehicle maintainability through the design process.

A design shortcut that provides a removable panel (using common screws to fasten the panel in place) appears to be simple and low cost. Manufacturing installs the panel, and maintenance staff then must remove multiple screws, and remove the panel each time maintenance is performed. Adding to that effort is the possibility of damaging the removed panel and/or damaging or losing the screws; the overall task may take much longer to perform. The simple panel is no longer low cost; at this stage, the cost is now transferred to the transit authority.

Now, consider the option for a locked, hinged maintenance panel with a hold open device. The design may take an extra few hours and manufacturing make take an extra hour to install it; now, however, maintenance personnel simply open the panel with a crew key. If the panel is accessed only once per 45 day maintenance activity (and the 45 day maintenance activity occurs daily on different vehicles, and the total time difference is 15 minutes per day), over 30 years, the total maintenance time would be 1,950 hours. A conservative shop rate of $60/hr gives a total expense of $117,000 over the life of the car. The unit cost difference in the new car price is likely less than $200 (45 day maintenance of one vehicle per day covers a fleet size of 32 cars using a normal work week, and one car maintained per day).

Standardizing component configurations opens the possibility of sharing components between vehicles in a fleet, up to project level sharing between transit authorities. Several owners (Utah Transit Authority, San Diego Metropolitan Transit System, and Denver Regional Transportation District) with the same type of Siemens light rail transit vehicles formed a Siemens Vehicle Owners group to facilitate information, parts, and equipment sharing. A vehicle not designed with maintenance considerations in mind may have features that cause maintainers to waste significant amounts of time and effort over the course of the fleet life.

Another strategy to address vehicle maintainability in the design process is to identify opportunities for standardization and simplification, such as the use of non-proprietary components and systems or modular components. Cross-functional design review can ensure such opportunities are identified. Examples of design considerations that may affect maintenance are outlined in **Table 2-2**.

Table 2-2. Vehicles Design Considerations that can Reduce the Total Cost of Ownership

System	Typical Design	Improved Design
Light fixtures	Multiple screws	Spring clips, catches, or maintenance key locks
Access panel	Prop rods	Automatic hold-open device (for example, gas springs)
Overhead access panel	Clip type, safety chains or cables	Spring latch type catches (for example, automotive hood catch)
Bolted connections	Limited access	Add wrench clearance, or holes for socket/extension access
Floating equipment panels	Threaded fastener mounting	Hinged and latched, or if screws are required, use locator pins for ease of remounting
Electrical connections	Terminal strips, junction boxes, and ring lugs	Secure connectors and multipin plugs
Threaded fasteners for frequent access items	Bolts, screws, and nuts	Spring clips, over-center catches, spring latches, and crew-key locks (“tool-less” access or mounting)
General assemblies	Multiple component assemblies – distributed	Unitized or packaged assemblies that may be disconnected, removed and repaired off-line
Diagnostics	Connections normally at the unit, multiple throughout vehicle	Single point, or single location diagnostics inside vehicle allowing quick access to all diagnostics
Lighting	Fluorescent, incandescent	LED lighting
Flooring	Plywood	Composite, encapsulated
Seating	Neoprene foam	Silicone foam
Equipment Enclosures	Carbon steel	Stainless steel
Batteries	Standard water capacity	Increased water reserves, improved watering systems
Motors	Standard ratings	Increased ratings via improved insulation

A systems approach helps to ensure that major procurements both successfully support overall agency goals and improve system performance. Robust requirements identification is a major component of a systems approach. In the case of revenue vehicle procurements, it is important to specify a vehicle that meets the needs of the overall transit system objectives with consideration for both present requirements and anticipated future needs.

Transit operators balance several competing factors in the acquisition of new revenue vehicles. The operators must forecast the magnitude and character of future transit demand and select vehicle capacities and aptitudes for particular operating environments, but they must offset these considerations against their current fleet composition, facilities, and existing maintenance staffing and capabilities.

Furthermore, fleet maintenance benefits from economies of scale, whereby having fewer models improves the ease of scheduling repairs and reduces the parts inventory and spare-vehicle ratio needed. Using the same manufacturer over multiple procurements can reduce the number of parts needed on hand and reduce training and complexity through standardization. Therefore, vehicle procurements—particularly bus procurements—can be valuable opportunities for cross-asset planning to assess forecasted transit needs and planned maintenance facility investments and to optimize investment decisions, which are all hallmarks of a systems approach.

Improved instrumentation of vehicle systems must be supported by improved data collection and reporting. The inspection, maintenance, and rehabilitation schedules of systems, such as air conditioning or fare collection, are not necessarily tied to vehicle hours or miles, but to independent use statistics. Agencies should ensure they capture all usefully operational data whether collected through the computer-aided dispatch system or the maintenance management system.

Robust risk assessment and QA/QC processes are intended to mitigate the likelihood of poor design decisions or manufacturing quality and identify potential and actual quality issues before they become the transit agency's responsibility. The specification, design, and manufacture of the vehicle together determine the final product the agency must use for operation and its cost of ownership. As an example of a vehicle procurement risk, the vehicle selected may eventually be identified as a "lemon" design—often related to the powerplant or powertrain—and quickly fail to meet reliability standards, leading to much higher maintenance costs. Thus, the vehicle procurement process can benefit from the use of appropriate risk management measures. The following technical and contractual risk management measures can mitigate such risks:

- If the procurement of a particular vehicle type is a first of its type by an agency (or if the type is new to the industry), it is prudent to procure a small sample order of vehicles to allow ample time to test in revenue operation. Reliability, Accessibility, Maintainability and Safety (RAMS) demonstration programs are specified to prove a new vehicle is reliable and maintainable. Such programs are primarily active once a vehicle prototype has been manufactured, and actual testing may be conducted. To get the most value from RAMS programs, there must be enough time allocated to properly service the RAMS demonstrations and make any corrections to the design that emerges out of the RAMS activities.
- The inclusion of tests and inspections by a qualified third party during the manufacturing process in the vehicle technical specification is one valuable strategy for risk management. As the vehicle is constructed, defects not observed by the manufacturer can be "covered up" by the continued manufacturing process. Such a defect may surface as an operational issue years after beginning service. As an example, vibration within the vehicle contributes to component failure (electrical connections become loose, electrical components fail, mounting brackets fatigue). Vibration effects can be mitigated within components by using vibration resistant designs, multipoint mounting systems, and vibration isolators. Including vibration testing requirements in procurement and a mandate to implement mitigation factors can improve reliability and lower operational and maintenance costs over the life of the asset.

In a competitive bid environment, vehicle manufacturers prepare the vehicle design based upon specification requirements and their internal budgets, including engineering, component, and manufacturing costs. These costs however are just a small portion of the total cost over the complete vehicle lifecycle. Adjustments made to the basic design criteria may increase base vehicle cost, but could significantly lower the overall cost of the vehicle throughout its life.

- Performance- or availability-based maintenance contracts with the manufacturer or another vendor are another way to limit risks and cost as well as reduce the required effort by the agency for the vehicle design in the procurement process. Such contracts fix the transit agencies costs over the contract term, which limits the risk of unexpected rising costs but also removes the opportunity to take advantage of falling costs, as might occur during a recession. Tire leases—whereby agencies pay the tire vendor for a tire supply by the mile—are an excellent example of this kind of financially based risk management approach.

Operations and Maintenance Considerations

A data-driven approach to maintenance is essential to identify performance issues, deploy maintenance resources efficiently, and improve maintenance procedures. The more vehicles in service for a given vehicle type, the more standardized maintenance practices tend to be. For example, a diesel-bus maintenance program may benefit more from broad industry practice relative to an electric trolley bus operation or a light rail service using diesel multiple units. In the initial deployment of new vehicles, maintenance is usually performed according to the maintenance manuals prepared by the vehicle manufacturer, especially for parts and systems still under warranty. As their experience with the new vehicles increases, transit maintenance departments can increasingly use maintenance and inspection data to understand whether they are performing preventive maintenance to the right level. With an effective maintenance management system and data collection processes, agencies have access to high quality data with which to assess their maintenance practices, identify maintenance issues and opportunities, and test new approaches. Reliability-centered maintenance is one framework for performance modeling and improvement, which focuses on reducing costs through scheduling preventive maintenance activities to maximize reliability and minimize the probability of an in-service failure.

Based on findings from its reliability centered maintenance program, one commuter railroad extended its air conditioning unit rebuilds from 5 to 7 to 8 (and most recently) to 10 years, thus realizing substantial savings without sacrificing reliability standards.

> To better predict the useful life of any particular system or component, maintenance planners can analyze historical maintenance data. When an in-service failure occurs, the initial failure report must accurately define the type of failure that was experienced. The ensuing maintenance report must be accurate and complete and include the diagnosis of the reported issue. A user-friendly maintenance management system with specific forms which, for instance, allow easy coding of failure causes and onboard vehicle diagnostic messages, combined with a disciplined maintenance culture with respect to careful and accurate data entry can together ensure that data collected are sufficiently detailed, relevant, and accurate. The data collected might include the findings of the actual failure mode, the resolution of the failure, and any failure analysis, testing or followup that is required. When labor and parts costs are also captured, planners can use this information to more accurately predict future fleet repair costs.
>
> Once these data are entered into a database, over a period of time, vehicle engineers can use the database to prepare a trend analysis of failure modes and component failures. Using the trend analysis, it may then be possible to predict the actual life of each component, assembly, or system (based upon actual operation). Likewise, condition assessments of systems and components can help time refurbishments and rebuilds.
>
> Once the useful life of these items is known, the preventive maintenance schedule is optimized to ensure that the components are replaced near the appropriate reliability threshold. This characterizes the evolution to predictive maintenance.

Having an accurate, up-to-date asset inventory integrated with the maintenance management system helps track issues over time. For vehicles, an asset inventory should extend to key vehicle subsystems and components and track install dates and use levels. Components and modular systems may be installed on multiple vehicles over the course of their useful life.

A reliability-centered maintenance approach can extend vehicle service lives, improve vehicle availability, and reduce maintenance costs through improved maintenance effectiveness, fewer costly in-service failures, and fewer maintenance hours per vehicle.Reliability data can also be used to track the performance of individual vehicles and help maintenance staff better address “problem vehicles” with persistent maintenance issues.

High-quality business processes and management control systems provide the basis for data collection and performance modeling. Proactive maintenance relies on data collected through the maintenance management system, effective data integration and analysis, and the insight of key technical staff to identify the root cause of issues and to propose alternative approaches. For example, a maintenance management system can help improve maintenance scheduling and resource allocation to improve efficiency. Many factors can affect the scheduling and execution of preventive maintenance tasks:

- Preventive maintenance requirements are intended to conform to manufacturer’s recommendations to maintain warranty status.
- Sufficient qualified manpower is allocated to the maintenance department.
- Ongoing training for mechanics and technicians is required to cover evolving vehicle technology systems.
- The maintenance department must have appropriate diagnostics equipment on-site in sufficient quantities.
- Parts inventories are managed effectively to minimize time to repair.
- Labor contracts may prescribe work rules and work schedules.
- Seasonal changes can alter daily cleaning routines and require interior and exterior “deep cleans” to maintain a satisfactory appearance to the ridership.
- Maintenance staff work schedules may not be adequately built around peak-vehicle availability and permit maintenance procedures to coincide with a single team’s shift.
- Vehicle rehabilitations are cyclical and can create an extended need for higher maintenance capacity.
- Heavy use periods, such as temporary road closures or sporting events, may increase maintenance requirements.

Querying and analyzing electronic maintenance records can identify the patterns behind such issues and suggest operational improvements within maintenance.

Many agencies have identified quality control of maintenance activities as a critical factor to improve reliability. Quality control focuses on two main issues:

- Efficacy of existing maintenance protocols – Vehicle maintenance staff or engineering teams should be able to track the effectiveness of maintenance approaches by querying the maintenance management system. By looking at maintenance records for a given system, it is possible to identify trends and outlier issues based on recurrence patterns and problem vehicles. Technical staff can then conduct a detailed analysis to identify the root causes and improve the maintenance procedure. As such updates occur, it is important to carefully document the root causes and update existing protocols and documentation.
- Quality of the work performed – Transit agencies can improve their training and documentation. Potential training improvement strategies include:

- Provide a common approach and baseline skillset via a standardized training program.
  - Pair inexperienced mechanics with top performers.
  - Provide rotation programs for maintenance staff to better understand their roles and the overall maintenance process.
  - Place more staff with quality control responsibilities on the shop floor.
  - Identify specific maintenance technicians in need of training to speed knowledge transfer and refine maintenance quality.
- Better documentation consists of carefully describing each maintenance procedure using clear language familiar to technicians, complementary photos and diagrams, helpful tips, and clear explanations for how the approach should occur. Documentation should be electronic so it can be kept up-to-date and should be available at easily accessible laptops or terminals at each bay or station. Many maintenance departments charge senior maintenance technicians with the preparation of protocol updates.
- Another approach to address quality of work issues is to employ designated quality assurance inspectors to perform inspections of defect repair processes and final repaired products. Since it is almost impossible to inspect every process or product, quality assurance staff should use a spot-check method, often targeted based on repair effectiveness data from the maintenance management system.

Table 2-3outlines some of the activities and circumstances that can affect the condition and performance of vehicles. When adopting standard asset management practices, agencies must still think broadly about what special circumstances and requirements exist in their operating environment. The factors outlined below are all important considerations for lifecycle management planning.

Table 2-3. Circumstances with Potential to Affect Cost and Performance of Vehicles

Lifecycle Categories	Circumstances	
Design and Construction Decisions	▪ Vehicle size and type ▪ Quality of materials and components	▪ Duty cycle and geographically oriented specification ▪ Quality tolerances in manufacturing
Operating Approaches	▪ Pre-trip and post-trip inspection ▪ Operator quality ▪ Fuel quality ▪ Wheelchair ramp usage ▪ Roadway or track condition	▪ Traffic ▪ Unintended impacts (vehicle hitting building) ▪ Train operations (acceleration and deceleration, frequency/severity of service, mixed traffic, loading conditions)
Maintenance Practices	▪ Level of preventive maintenance ▪ Predictive component changes (before failure) ▪ Daily servicing (oil check, fueling)	▪ Vehicle cleaning practices ▪ Maintenance practices
Miscellaneous	▪ Vandalism ▪ Road and track condition ▪ Natural environment (ground water, rain, flooding and excessive heat caused by direct exposure to the sun, seasonal changes [cold and hot weather], abusive use and poor or lack of routine maintenance from water leakage and corrosion)	

Collaboration and information sharing are important ingredients for better vehicle maintenance performance. Establishing joint responsibility can help promote problem solving and more effective resolution of issues as they arise. Some rail transit agencies have found it helpful to improve the transparency of their vehicle engineering teams' work and their integration with other teams. Maintenance technicians, managers, and other staff can submit issues for engineering analysis and track them through the engineering process. Engineering documentation from past analyses is freely available within the maintenance department and is both indexed and searchable. As improvements are identified and implemented, information in the maintenance manuals should be updated and supplemented, and maintenance staff kept up-to-date and fully trained.

Collaboration and information sharing can also help manage supply chain issues related to maintenance. Effective management of the parts inventory is critical to ensuring necessary parts are on hand to the extent possible in order to minimize the time to repair. Integrating inventory functions into the maintenance management system is one important step to improving coordination and efficiency. However, direct collaboration between the shop floor and the parts department can provide a conduit for valuable qualitative feedback and support ongoing process improvement.

Capital Rehabilitation and Replacement Considerations

Maintenance planners may need to use a systems approach to effectively address the complexity of defining an optimal rehabilitation process. To maximize the cost-effectiveness of a rehabilitation program, it is necessary to identify appropriate systems and components for inclusion, establish the rehabilitation approach accounting for the benefits of refurbishing or replacing vehicle systems and components at the same time, and establish an appropriate timeline with sufficient space and labor resources, while maximizing ongoing vehicle availability. For instance, a schedule of targeted overhauls of specific items or systems spread out over the life of the car can reduce overall maintenance cost by reducing the downtime of the vehicle, and allow the targeted assembly to be overhauled at the optimal time in its own lifecycle.

> In some cases, rehabilitation may be fairly comprehensive and include overhaul of body, flooring, undercarriage, powertrain, electrical, and HVAC. In other cases, specific areas of concern may be identified as problematic for the fleet and may be targeted for rehabilitation campaigns.
>
> The need for an area-specific rehabilitation or campaign is established through the collection of historical data as discussed earlier in this section. Such a program can enhance the efficiency of the lifecycle or reliability-centered maintenance plan by keeping maintenance schedules tied to the true needs of the systems and components and avoid down cycles driven by the replacement of degraded components.
>
> Maintenance planners must establish logistics to accomplish the work, including availability of parts and manpower and vehicle availability. Once this information is assembled, an agency must decide if it is more cost effective to perform the work in-house or through an outside vendor.
>
> Modular assemblies are one approach to not only reduce maintenance downtime but to make targeted overhauls much more effective. Modular systems can be removed from the vehicle, overhauled, reworked, or upgraded off-line with less effect to the vehicle availability or revenue service. The unitized assembly can then be changed out with less interruption to normal maintenance activities. Agencies should have an effective asset inventory system in place to track these components' history through maintenance and across vehicles.

Implementing maintenance in this manner may also require reconfiguring shop facilities and readjusting work assignments among crafts and shifts. To help plan such programs, maintenance managers can query their maintenance management system to estimate labor resources needed and plan vehicle availability.

An effective maintenance management system and qualified maintenance planners can be used to optimize the timing of rehabilitation and replacement. For vehicle subsystems and components that might need only overhaul or replacement once or twice (if ever) within the useful of a vehicle, inspections and tests can be an important tool to determine timing. In some cases, long-term collection of performance and wear data can help establish the proper threshold at which the rehabilitation should occur. For instance, an earlier engine rebuild based on performance data might increase vehicle reliability and improve fuel efficiency, thereby generating cost savings. Transit agencies should carefully monitor initial vehicles delivered for a particular model because early data can define maintenance management for the remaining fleet.

Condition Assessment and Performance Monitoring

Having a strong data-collection infrastructure and accurate asset inventory in place is an important step in condition and performance monitoring and is a critical foundation for transit asset management. Data collection activities include capturing data from scheduled inspections tied to specific systems and components, daily maintenance data collected through the vehicle maintenance management system, and additional data from onboard vehicle systems and diagnostics, stand alone sensor systems, and ad hoc testing and inspections. Scheduled inspections follow checklists of specific tests, visual inspections, and measurements.

Data collection supports specific business needs including monitoring of safety, reliability, asset condition, customer-readiness, and other factors related to operational performance. Management systems should be integrated to provide a single, consistent repository for data in a master database.

Such data may be integrated to varying extents through the maintenance management system, but regardless should be easily available digitally across the agency, for instance through standard system reports or shared server folders. Open access to data across the organization is an important principle of condition and performance monitoring.

The data collected are then available for analysis and synthesis into the performance monitoring program. The performance data and failure trend analysis that are based upon preventive maintenance and repair of discrete systems, assemblies, and components, can be used to supplement the overall condition assessments by adding statistical data to the actual inspections performed.

Condition measures can be a valuable benchmnark of the effectiveness of an agency's lifecycle management practices and investment needs. Transit agencies commonly apply condition measures to overall vehicle condition and to a very limited set of specific components (such as tires). As an agency improves its data collection, tracking condition can become easier and can be a valuable strategy for improving maintenance timing and cost-effectiveness, along with fleet management and capital planning. Condition measures should map to the vehicle asset inventory as closely as possible. Condition scores may be qualitative, but they should be linked both to a vehicle or a fleet's capacity to meet performance goals and to specific resultant actions. For purposes of funding prioritization, a transit agency may want to use condition measures that are comparable across asset classes.

For an individual component, the condition measure indicates whether the part or system is functioning properly and whether any action is needed. For instance, brake pad thickness indicates whether the pads are safe and how much of their useful life remains until they must be changed out. Particular thickness ranges are associated with distinct actions, such as immediate repair, scheduled repair, or no action.

For an individual vehicle, the condition measure should indicate the vehicle's preparedness to deliver service in line with the agency's goals of safety, reliability, operating performance, and customer satisfaction so that the transit agency can prioritize vehicles for maintenance and rehabilitation. Individual agencies can aggregate available data into a condition index usually based on condition inspections and maintenance records. Using one condition scoring approach, maintenance staff can categorize each vehicle system as ready for service, mostly ready for service, or not ready for service. The aggregate vehicle score then takes into account whether any critical systems are fully ready for service and classifies the vehicle accordingly, often on a scale of 1 to 5, where a score of 3 or above indicates the vehicle is available for revenue service. Another vehicle condition score might just be the measure of the vehicles' reliability over the past 2 years, allowing easy comparison among vehicles.

To assess a fleet's preparedness to meet agency goals, a simple condition average is not sufficient. An example of a more useful measure for management would be the percentage of vehicles meeting a minimum condition index score—an availability metric that provides a more direct measure of the ability of the agency to deliver service, which the transit agency can use to set maintenance and rehabilitation budget levels.

Condition assessments or inspections should be regularly scheduled to complement the overall preventive maintenance requirements used to ensure the maintenance requirements are effectively implemented, and also used to identify any component or system trends that would lead to deficiencies in the currently planned maintenance for the vehicle.

Periodically through the life of the vehicle, a more comprehensive condition assessment should be performed to determine the condition of major subsystems and equipment. These condition assessments are slightly different than the overall inspection performed during routine maintenance; they consider the degradation of performance that would normally occur as components wear out. For example, engine dynamometer tests can help assess the need for and effectiveness of engine rebuilds. Third-party inspections by a qualified maintenance consultant can provide an objective analysis of the agency's maintenance practices and help benchmark in-house inspection and maintenance processes against other agencies and contractors.

Table 2-4 outlines some of the performance metrics an agency can use to measure how well the vehicles are meeting their level of service requirements both at the individual vehicle and fleet levels.

Table 2-4. Vehicles Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics	
Vehicles (All)	▪ Overall appearance meets established operational criteria ▪ Correct operation of systems, assemblies, and components ▪ Successful passing of test requirements ▪ Vehicle age ▪ Targeted inspections for wear items	▪ Mean Distance Between Failure ▪ Mean Time Between Service Delay ▪ Vehicle availability ▪ Change in power/fuel consumption ▪ Overall vehicle/fleet availability ▪ Change /increase in relevant failures ▪ Change in Mean Time To Repair ▪ Ratio of maintainers/vehicle	▪ On-time performance ▪ Fleet defects (against specific thresholds) ▪ Inventory costs per vehicle (overall and by fleet) ▪ Spares ratios ▪ Maintenance labor hours / vehicle ▪ Maintenance cost / vehicle ▪ Scheduled versus unplanned maintenance costs

Quality assurance and quality control measures ensure that vehicle maintenance staff is adhering to business processes and properly completing inspections, maintenance, and rehabilitation activities. For in-house or contracted maintenance situations, one facet of quality assurance for vehicle maintenance is having third parties conduct regular audits of vehicles to ensure appropriate maintenance and inspections are taking place and that repairs are being performed properly. Agency in-house quality assurance inspectors should perform spot-check inspections of repair jobs and component rebuilds. Inspectors can also verify the quality of parts being used.

Quality assurance and quality control is even more important during the vehicle procurement process. When a vehicle is being manufactured, thorough inspection processes can ensure design and maintainability requirements are met and risks of asset failure are mitigated. The following are inspection considerations:

- Professional inspectors should be hired with a minimum of 5 years of transit maintenance experience.
- Inspectors should work full time during inspection period.
- Inspection should commence at cutting and treatment of steel foundation.
- Each subsequent manufacturing process should be monitored and inspected for content and quality.
- During the inspection process, the inspector should ensure that the technical specification has been met or exceeded.
- All required testing should be witnessed by an inspector.
- The inspection should end when the manufacturer offers the completed vehicle to an agency's inspector for inspection with no defects. This must occur before the vehicle is shipped to the owner's property. In many cases, the agency requires an "incoming inspection" when the vehicle arrives on-site to ensure no damage occurred en route.
- Contract inspectors should be dedicated to one build of vehicles at a time so that they can concentrate on one specification.

2.3 Industry Standards

The following list provides examples of industry standards associated with the vehicles asset class:[1]

- **Rail Vehicles & Fixed-Guideway Non-Revenue Vehicles**
  - American Public Transportation Association (APTA) Manual of Standards and Recommended Practices for Rail Transit Systems: Represents an industry consensus on practices and standards to help rail transit systems achieve a high level of safety. Topics covered include vehicle inspection maintenance, rail grade crossing, operating practices, and inspection and maintenance for fixed structures and signals.[2]
  - American Association of Railroads Manual of Standards and Recommended Practices: Includes standards for the design, fabrication, and construction of freight cars, maintenance and rehabilitation, and management practices.[3]
  - Federal Railroad Administration (FRA) Regulations for the Safety of Railroads: FRA issues regulations that govern mechanical equipment that includes locomotives and rail cars. Other regulations pertain to track, wayside signal and train control systems, highway-rail grade crossing automatic warning device systems, and railroad operating practices.[4]
  - American Railway Engineering & Maintenance-of-Way Association (AREMA) 2012 Manual for Railway Engineering: Serves as a guide of recommended practices for rail planning and covers four main topics: track, structures, infrastructure and passengers, and systems management. Within the topic of infrastructure and passengers, vehicle considerations and maintenance of equipment are discussed.[5]
  - American with Disabilities Act (ADA) Accessibility Guidelines for Transportation Vehicles: Establishes regulatory guidelines for rail and bus features such as door width, priority seating signs, and lighting to accommodate persons with disabilities.[6]

- **Buses, Paratransit & Non-Revenue Vehicles**
  - American Public Transportation Association (APTA) Bus Standards: Includes standards for bus procurement, maintenance and safety, and operations. [7]
  - Federal Motor Carrier Safety Administration Regulations[8]
    - Inspection, Repair, and Maintenance Regulations: systematic inspection of vehicles to ensure that vehicle parts are in working order at all times.[9]
    - Parts and Accessories Necessary for Safe Operation Regulations: establishes safety standards for parts such as lighting, electrical wiring, brake systems, windows, tires, and others.[10]
  - Federal Motor Vehicle Safety Standards: Safety standards and regulations for a motor vehicle's design, construction, and performance to meet minimum safety performance requirements and protect the public against unreasonable risk from crashes.[11]

---

[1] This supplement defines industry standards as requirements, standards, or guidelines that exist currently or are pending.
[2] http://www.aptastandards.com/Documents/PublishedStandards/Rail/tabid/327/language/en-US/Default.aspx
[3] http://www.aar.org/Operations/AAR-Industry-Standards-Freight-Loading.aspx
[4] http://www.fra.dot.gov/Pages/1762.shtml
[5] http://www.arema.org/publications/mre/index.aspx
[6] http://www.access-board.gov/transit/html/vguide.htm
[7] http://www.aptastandards.com/StandardsPrograms/BusStandardsProgram/tabid/57/language/en-US/Default.aspx
[8] http://www.fmcsa.dot.gov/rules-regulations/administration/fmcsr/FmcsrGuideDetails.aspx?menukey=390
[9] http://www.fmcsa.dot.gov/rules-regulations/administration/fmcsr/FmcsrGuideDetails.aspx?menukey=396
[10] http://www.fmcsa.dot.gov/rules-regulations/administration/fmcsr/FmcsrGuideDetails.aspx?menukey=393

- State inspections requirements include:
  - California Highway Patrol bus maintenance and safety inspection[12]: Safety-focused inspections for all public and private carriers.
  - New York Department of Transportation Bus and Passenger Carrier Safety inspections: Mandatory safety inspections covering school buses, public buses, and private passenger carriers.[13]
- Federal Transit Administration (FTA) Standards and Testing: Buses must meet minimum standards for service life and undergo requirements and maintainability testing for quality control.[14]
- Environmental Protection Agency (EPA) Emissions Standards for Heavy Trucks, Buses, and Engines: Sets standards for pollutants resulting from diesel exhaust. Non-conformance penalties for exceeding the established limits of nitrogen oxides are also included as part of the regulations.[15]
- Americans with Disabilities Act (ADA) Accessibility Guidelines for Transportation Vehicles: establishes regulatory guidelines for rail and bus features such as door width, priority seating signs, and lighting to accommodate persons with disabilities .[16]

The Fairfax County Department of Transportation s (FCDOT) Fairfax Connector" uses scheduled maintenance activities to maintain their revenue rolling stock, supporting cleanliness, reliability, and economics of operation. The agency provides transit and park and ride service for Fairfax County, Virginia, which is located on the western side of the Washington, D.C., metropolitan area. The transit operation is midsized with 250 buses domiciled at three operation and maintenance facilities all operated by a contractor.

The agency owns all assets included in the operation and maintenance of the service. Rolling stock assets and support equipment are owned by the agency and maintained by the contractor or their subcontractor.

The contract between FCDOT and the operations and maintenance contractor requires specific performance levels for operating and maintaining the service and rolling stock. The maintenance requirements (intervals and parts) of the rolling stock are contained in the contract and include not only routine daily service, scheduled cleaning, and scheduled inspections with fluid changes and fluid analysis, but also scheduled service of major sub assets (e.g., HVAC, ADA). The contract also contains predictive maintenance change out of components throughout the life of the asset. Trend analysis and geographic location equipment specifications were used to determine the intervals included in the contract and are dynamic; based on additional experience, they may be adjusted. The contract also includes targeted lifecycle disposal/replacement dates so the contractor can budget for maintenance activities. Non compliance to certain contract goals have specified penalties that may be assessed by the agency.

FCDOT maintains a contract with a third party firm for technical support in the maintenance of the fleet. This includes new bus specification development, new bus online manufacturing inspections, delivery inspections, fleet equipment in service condition assessments, and other tasks associated with maintaining the rolling stock.

The result is that the agency has experienced an improvement in the cleanliness, mechanical condition, and performance of its rolling stock. The contractor can better budget for maintenance activities through the lifecycle of their contract. The equipments condition and reliability has improved since its inception. The parties maintain a good professional working relationship as the roles of each are spelled out in the two contracts and understood by each.

[11] http://www.nhtsa.gov/cars/rules/import/fmvss/index.html
[12] http://www.chp.ca.gov/publications/pdf/chp108a.pdf
[13] https://www.dot.ny.gov/divisions/operating/osss/bus/inspection
[14] http://www.gpo.gov/fdsys/pkg/CFR-2009-title49-vol7/pdf/CFR-2009-title49-vol7-part665.pdf
[15] http://www.epa.gov/otaq/hd-hwy.htm
[16] http://www.access-board.gov/transit/html/vguide.htm

Chapter 3

Facilities and Stations

3.1 Asset Class Overview

Facilities and stations refer to the structures that enclose or support maintenance, operations, administrative, and public spaces. Stations provide shelter for employees and customers, and facilities provide shelter for employees, revenue vehicles, and power systems. Facilities also house specialized equipment that support the operations and maintenance of the vehicles (for example, fueling and wash facilities). Maintenance work spaces must accommodate vehicle movement within and around buildings, industrial workflow, and storage and use of a variety of maintenance equipment. Service facilities may include industrial workspaces similar to maintenance facilities, storage areas, and office spaces. Passenger facilities are usually focused around spaces for pedestrian movement or waiting. Stations and other passenger facilities are particularly important because they directly impact the customer experience.

Every facility is composed of structural elements and building systems. These component elements have separate asset management requirements that should be addressed through lifecycle management planning. Structural elements include the core structure and component elements such as the roof, windows, and foundation. Facility systems may include HVAC, electrical, piping and plumbing, drainage and pavement, fire protection, fencing, landscaping, safety and security systems, and elevators and escalators. Besides the facilities themselves, some of the most critical sub-assets include fixed equipment such as vehicle lifts, fueling equipment, storage tanks, and vehicle washers.[17]

The asset classes include the following:

- **Rail Vehicle Maintenance Facilities** – This asset class refers to the structures used for maintaining steel-wheeled fixed-guideway revenue vehicles (for example, commuter railcars, locomotives, electric and diesel multiple units, and streetcars) and supporting shops.
- **Rubber Tire Vehicle Maintenance Facilities** – This asset class refers to the structures used to maintain rubber-tired revenue vehicles (for example, over-the-road coaches, articulated buses, municipal buses, paratransit buses, and vans) and supporting shops.
- **Service Facilities** – This asset class refers to all structures not covered in the previous two bullets. These include, for example, facilities addressing the following functions: non-revenue maintenance support, maintenance-of-way and buildings and grounds field crew, operations offices, administrative facilities, operations central control, and central warehouses.
- **Stations** – This asset class refers to structures intended primarily for passengers' use, including bus transfer facilities, rail stations, and customer service facilities.

Because of the unique functional requirements for most transit facilities, transit agencies tend to manage most of their facilities throughout the entire facility lifecycle rather than acquire and dispose of them as needed. Therefore, agencies are typically involved in the facility design, operation, maintenance, renewal, and replacement. In many cases, transit agencies lease their facilities (especially administrative office space) either in the private market or in public buildings, as in the case of agencies that are part of local government. More often, most or all transit facilities and stations are owned by the transit agency. However, the functions within the facility may be outsourced, including the maintenance of the facility. In all cases, even where the transit agency's maintenance responsibilities may be limited, it is still worth considering the value of deploying various facilities asset management practices to cost-effectively ensure the facility's performance and manage risk.

Lifecycle management planning, usually documented in a facilities management plan, may cover individual facilities or provide a general plan for all facilities or a class of facilities and outline an asset management approach for each type of facility element. In the case of new construction, the contractor can be required—as part of the acceptance process upon completion of construction—to provide a facilities management plan covering preventive maintenance and inspection requirements. Alternatively, the transit agency may develop a general approach applied to all facilities.

As is the case in other industries, facilities not used by customers typically have lower investment priority and, as a result, have more deferred maintenance and are more likely to be used beyond their intended useful lives. However, maintenance of key building systems can have a dramatic impact on the overall facility's service life and ability to meet minimum safety requirements. For example, repainting and roof replacement can be critical to maintaining the building envelope to prevent water infiltration and resulting structural damage. Fortunately, asset

[17] This supplement does not cover parking structures and other facility assets that are common outside of the transit industry; however, most of the same facility asset management principles will also apply to those assets.

condition monitoring and assessment is well understood with well-developed standards for most building systems. As a result, investment needs and tradeoffs for facilities are relatively easy to quantify in support of facilities management plans and performance-based asset management.

A facilities asset inventory tracks individual assets and asset management activities. An asset inventory provides a foundation for the implementation of the facilities lifecycle management plan. When developing a facilities asset inventory, it is important to consider how assets are defined. Beyond assigning facilities' assets functionally to modal divisions or the general operations category, assets may be classified by location and by their owner or manager. Furthermore, facilities' assets should be defined to a level of detail that coincides with critical maintenance activities to give a more accurate representation of facilities' condition and of the nature of maintenance and investment needs. For example, grouping separate roof structures on a single facility as a single asset—especially if they are of different construction—would preclude tying each roof structure back to differing maintenance performed at different times. When inventory assets can be easily mapped to prior maintenance activities and condition scores, inspection and maintenance activities as well as the development of project lists and the prioritization of needs can be planned. All of the asset classes included in the facilities and stations category are organized in a proposed asset classification in **Table 3-1**. Note that many functional asset classes may be grouped together into a single facility.

Table 3-1. Facilities and Stations Asset Classes' Proposed Asset Hierarchy

<table>
<tr><th>Asset Class</th><th>Sub Assets</th><th>Related Assets</th></tr>
<tr><td>Bus and Rail Vehicle Maintenance Facilities</td><td>▪ Buildings
▪ Civil improvements
▪ Access roadways
▪ Parking lots/structures
▪ Offices
▪ Restrooms
▪ Elevators and escalators
▪ Maintenance equipment</td><td rowspan="3">▪ HVAC (refrigeration and heat-generation equipment, distribution systems, instrumentation and controls)
▪ Electrical (lighting, power distribution, emergency/backup power sources, and renewable energy systems)
▪ Piping and plumbing (sprinkler and fueling systems)
▪ Drainage and paving
▪ Exterior envelope and structure (roof, windows, structure, foundation)
▪ Safety and security systems
▪ Railcar turning table
▪ Vehicle lift
▪ Vehicle washer
▪ Paint booth
▪ Furniture, fixtures, and equipment</td></tr>
<tr><td>Service Facilities</td><td>▪ Access roadways
▪ Parking lots/structures
▪ Concourse and/or mezzanine levels
▪ Offices
▪ Auxiliary and/or equipment rooms/yards
▪ Restrooms
▪ Spaces designated for use by other departments
▪ Elevators and escalators</td></tr>
<tr><td>Stations / Passenger Facilities</td><td>▪ Stations
▪ Stops
▪ Access roadways
▪ Parking lots/structures
▪ Concourse and/or mezzanine levels
▪ Below-grade structures
▪ Offices
▪ Dispatch and operations
▪ Auxiliary and/or equipment rooms/yards
▪ Restrooms
▪ Spaces designated for use by other departments
▪ Platforms
▪ Concessionaire spaces
▪ Elevators, escalators, and moving sidewalks</td></tr>
</table>

3.2 Lifecycle Management Practices

New facilities are usually the product of a major system expansion or enhancement of the existing transit system. Facility design choices are based not only on the expected operational functions but also on local environmental factors and the diversity of construction practices. Changes in construction practices and building technology over time often mean a transit agency's facilities vary not only in function and age but also in design, construction type, and building system technologies, resulting in heterogeneous maintenance requirements. In general, transit agencies must balance the opportunity for substantial customization of facilities to complement their specific operational needs and context with the benefits of standardization of various building systems and components within and between facilities.

Transit agencies may have full-time staff to perform inspections, operate facilities, and undertake less intensive maintenance on an ongoing basis; however, many outsource all or a portion of these functions. Most major facilities maintenance projects are included in the capital program and are scheduled well in advance. A greater portion of facilities maintenance is capitalized in comparison to vehicle maintenance, which usually falls under operating cost. Transit agencies typically use facilities rehabilitations and renovations not only as an opportunity to address the facility condition but also to update its functional capabilities to better match the agency's current and expected operational needs. The end-of-life phase of a facility lifecycle usually involves planning for the replacement, adaptive reuse, disposal, or sale of the facility.

Facilities are complex aggregations of component systems and structural elements with diverse management and maintenance needs. This diversity means that the components should not necessarily share a single management approach. For example, energy-efficient operation of buildings applies primarily to the HVAC and electrical systems, so energy-use management programs typically cover only these systems. However, many agencies manage building maintenance through a single maintenance-management or work-order system. The following sections describe the lifecycle activities and considerations that are specific to facilities and stations for each of the asset classes and address some of the organizational and management approaches specific to facilities asset management.

3.2.1 Bus and Rail Vehicle Maintenance Facilities and Service Facilities

Bus and rail vehicle maintenance facilities are typically complex facilities with at least one primary maintenance shop, often several supporting shops, storage space, major equipment including vehicle fueling, washing, and maintenance equipment (for example, lifts, dynamometers, and railcar turntables), and operations and administrative space—all of which may have separate maintenance requirements. Other major facility features include maintenance bays with significant building openings to the exterior, maintenance pits, guideway elements like track, large open yard areas (paved or unpaved), and security elements like fencing, exterior lighting, and surveillance cameras. Rail operations may require additional maintenance facilities for the right-of-way, which frequently resemble a public works yard in layout and functions. Other rail service facilities to house utilities are usually located adjacent to the right-of-way. Administrative offices and operations facilities (dispatch, train control, training rooms, and security) are sometimes housed in standard office space and are often in leased spaces. Maintenance facilities are typically built to last at least 50 years or many times the life of the agency's normal revenue vehicle, but component systems may have much shorter design lives.

This subsection outlines lifecycle management considerations for the design, preventive maintenance, rehabilitation, and condition monitoring of bus and rail facilities with a focus on maintenance facilities. However, much of this section applies to facilities in general, including passenger facilities.

Design and Procurement Considerations

Transit agencies can address facility maintainability and expected lifecycle cost in the procurement stage through developing detailed performance specifications and including these factors in the selection criteria for design and construction teams. The minimization costs in the procurement stage (or in other stages of the asset lifecycle) should not be offset by greater expense later on in the lifecycle. In many cases, responsibility for future costs fall under another department, so transit agencies must nurture a culture that supports a holistic view of the asset and a commitment to agencywide—not just departmental—goals. Standards and ratings for high energy use systems (like HVAC) now bring transparency to the financial implications of purchasing decisions. Future costs for facilities, because of their long, useful lives, may be discounted significantly; however, the benefits should be modeled realistically as part of formal analyses of the total cost of ownership.

Once construction of a facilities project is underway, quality assurance and quality control measures (QA/QC) are essential to manage lifecycle costs. Lifecycle management planning should address QA/QC at every lifecycle stage. The construction phase is a critical risk period for any major facilities project. Corrective action costs decrease when a defect is discovered early and increase as design and construction proceeds.

> Transit agencies should have a robust QA/QC program in place to cost-effectively manage these risks and ensure all work is completed according to specifications using standard or best practices. For example, contractors may fail to verify the quality of concrete used in construction, and structural steel work needs careful quality control of welds and joints.
>
> Transit agencies may rely on third-party expertise or on the general engineering contractor for inspections. It is important to have a system in place for tracking issues from identification through followup to closure or resolution.

A systems engineering approach can help optimize facilities for operational needs. Facilities are primarily work spaces for transit operations, maintenance, and administration activities, which define the agency's operational efficiency. Major facilities investments are an opportunity to define operations for a generation and are therefore an opportunity for the transit agency's major functional divisions to collaborate to establish a coherent vision, balance their needs, and improve their approach to service delivery both within the agency and to customers. A systems engineering approach drives improvement by precisely defining facility functional needs, mapping work processes within the facility, and conducting iterative design reviews.

> At the facility level, the design should support the intended functional use to not only minimize the operating costs of utilities, maintenance needs, and staffing, but also to maximize the efficiency of the work space.
>
> Improving vehicle flow, minimizing dead space, grouping related activities, and facilitating process flows can also drive facility performance and efficiency.
>
> When designing a facility for a multifacility agency, it is important to consider the entire system and the relationship among the facilities (for example, how vehicles and parts flow among them) and their ability to support operations (for example, level of deadheading required).

Transit agencies can use performance measures to ensure accountability for the agency's asset management goals in the design and procurement stages. When possible, transit agencies should develop performance-based specifications to outline detailed operational requirements of facilities (for example, vehicle washers must be able to run a train through the washer at 3 miles per hour and use only 12 gallons of soap per vehicle washing). Such specifications should reflect a well-developed understanding of a facility's operational requirements (both existing and future).

The facility's users will be most familiar with capacity and performance issues in existing facilities. Design teams may find significant value in reaching out to diverse operations and maintenance staff representing key functions to set facility performance standards and evaluate facility design and identify potential issues. Such an approach can pre-empt the need for corrective investments later on, improve safety, and realize savings from the facility's higher productivity. It can be helpful not only to establish formal design review processes for facility operation and maintainability as part of initial project planning, but also to support a culture of collaboration that encourages consultation of internal resources, transparent procurement processes, and open communication.

One performance improvement strategy is to pursue standardization and simplification of facilities elements and processes to reduce costs. Standardization and simplification can be applied across a range of assets and systems to realize multiple benefits:

- More standardized equipment and components reduce the need for specialized maintenance, make training of maintenance personnel easier, and require fewer parts on hand.
- Maintenance staff can respond more quickly to issues, knowing the component involved and what parts will be needed.
- Simplified operations make it easier for facilities maintenance managers to provide robust documentation and procedures and thus support better quality control of maintenance activities.

Risk assessment and mitigation is an essential exercise for critical facilities assets. If for any reason a vehicle maintenance facility were unavailable, it might be impossible to deliver transit service. Furthermore, transit services can play an important role in general disaster response, so it is important to minimize the likelihood of a service outage coincident with a general regional emergency or disaster. Risk assessments can identify threats to facility availability and reliability both in the design phase and throughout the facility lifecycle. Facility siting is an example of a consideration that a risk assessment is intended to cover. For instance, as climate change shifts flood recurrence intervals, it is important to be aware of floodplains. Facility flooding is one of the most common causes of a transit maintenance facility shutdown. Design teams should also consider drainage on the property and ensure necessary slopes are in place. Maintenance facilities should not need recourse to drainage pumps, which are costly and can be unreliable. Recognizing that most transit agencies occupy legacy facilities and that conditions are often dynamic, regular risk assessments can help identify potential flooding, drainage, and security issues and provide an opportunity to craft cost-effective mitigation strategies to implement as part of facility renovations or rehabilitations.

Maintenance and Monitoring Considerations

If possible, facilities managers should use a maintenance management system to track facility maintenance requirements and schedule maintenance activities and projects. Facilities management software is one approach to integrate the complex management of diverse facility asset elements.

> Facilities management applications support condition assessment and preventive maintenance schedules, work-order processing, parts and equipment inventories and ordering, and a facilities asset inventory.
>
> The systems can also support performance monitoring of facilities asset management practices and facilities operation. For instance, building automation systems are commonly used to log maintenance issues, troubleshoot system anomalies and failures, provide remote access to

controls, monitor energy use and air quality, and even to track electrical leakage from distribution systems.

Performance measures are critical for tracking implementation of the facilities management plan. Performance reporting is an important process to ensure adherence to scheduled inspections, maintenance, and renovations and rehabilitations.

The percentage of preventive maintenance completed on time shows adherence to maintenance schedules and can identify issues with resource allocation.

Transit agencies should closely track the maintenance and investment backlog on each facility. The current maintenance and investment backlog is an important performance indicator that helps facilities maintenance staff to prioritize work, request appropriate budget levels, and advocate for important capital projects.

Condition measures provide a basis for measuring the effectiveness of maintenance procedures over time, helping to identify issues with particular maintenance staff or contractors or with the selected maintenance treatment itself.

Coordination among departments can help support the success of a lifecycle-based approach to facilities asset management. Depending on the scale of the transit agency, responsibility for various aspects of facilities management may be distributed throughout the organization. For instance, transit agencies often have dedicated facilities maintenance departments but may also have a real estate group or manager making property purchase and sale decisions, a right-of-way maintenance department maintaining passenger facilities, and an engineering or capital projects group overseeing the design and procurement of facilities. Improving coordination can also contribute to facilities upkeep and performance by identifying maintenance issues, communicating them to the responsible party, and ensuring workspaces meet their users' needs. Facilities management plans should clearly identify the responsibilities of each stakeholder and define the processes for collaboration.

Transit agency's investment and preventive maintenance programs for facilities should, to some extent, reflect a risk-based approach. A facility system's or element's risk priority increases with the likelihood of its failure and the severity of the consequences of such a failure. Condition measures are one way to measure risk but do not necessarily capture the underlying causes.

High-risk facilities systems need more frequent inspection, may warrant proportionally higher preventive maintenance resources, and should be targets for upgrading or replacement. For instance, fuel systems and hazardous materials have strict regulatory requirements for storage and handling.

Facilities managers are responsible for ensuring that storage areas and systems are maintained carefully, that the transit agency remains in compliance and proper records are kept, and that spill plans and disposal procedures are up-to-date. Relatively frequent inspections can reduce the risk of environmental hazards and safety hazards.

Another example of risk-based prioritization is the maintenance (before high rainfall seasons) of drainage systems to prevent flooding and of the building envelope to prevent water infiltration.

Capital Rehabilitation and Replacement Considerations

Decision analysis can be an important tool to support the timing of major rehabilitation and replacement projects. Transit agencies should maintain comprehensive and prioritized project lists for all facilities covering the short- to medium-term horizon. Major facilities projects typically grow out of long-range planning efforts. Asset management planning applications are available to model investment scenarios, including asset condition outcomes and operations and maintenance cost implications. It is important to review project lists regularly to revise prioritization based on up-to-date condition information, risk assessments, and agency operational needs and to identify opportunities to modify and consolidate projects to deliver the capital program more cost effectively.

> The transit agency often has some degree of flexibility for the new facility's development timeline and may be in a position to take advantage of the fact that the facility's capital costs can fluctuate widely based on general construction market conditions and underlying commodity prices. To the extent that transit agencies can time rehabilitation campaigns and facility replacements with market conditions, the agency may realize significant savings relative to peak prices when competing with general construction demand for labor and commodities (like steel).
>
> On the other hand, delaying critical investments and operating facilities assets beyond their useful life can have serious consequences. While the impact to an agency's financial bottom line may not be immediate, the change in risk profile is real and should be tracked through condition reports and addressed in capital program prioritization. While transit agencies can establish reliability thresholds for many of these assets based on their own data, condition inspections and manufacturers' recommendations can provide useful guidelines. The failure of a critical asset such as a lift can have an immediate operational impact and a lengthy recovery time.

Performance modeling can help maximize the value of facility renovation and rehabilitation projects by supporting evaluation of enhancement features. There is often significant latitude for redesign or a new approach when facilities are renovated or replaced. Unlike a vehicle that requires a specific component with exact specifications, a building can often accommodate a variety of alternatives. For instance, the installation of a significantly different HVAC system with modest incremental cost might yield large net savings from energy efficiency. Likewise, the overhaul of elevators and escalators (at approximately 25 years) is an opportunity to review available technologies and costs to evaluate upgrade and replacement options in comparison to a straight overhaul. For these reasons, the capital rehabilitation and replacement of facility elements may share the same design approach as new procurements. Rehabilitation and replacement is an opportunity to improve a building's operating costs, improve its workspaces' efficiency and environment, and prepare to meet the agency's future needs. Collaboration among the design and procurement teams, the facility management team, and the facility users is critical to take advantage of such opportunities. Also, because these facilities are critical to daily transit operations and often have limited off-line hours, facility maintenance, renovation, and rehabilitation can require either working around operations or partial or full diversion of maintenance activities to alternative or temporary facilities.

Setting initial schedules and estimates for facility renovations, rehabilitations, and other investments in the facility's management plan can provide valuable benchmarks over the facility's lifecycle. For example, chillers typically need to be overhauled at 15 years and replaced at 30 years, cooling towers need to be replaced every 20 years, pumps should be overhauled every 15 to 20 years, and furnaces should be replaced every 15 years. Ideally, this planned baseline is also mapped into the facility's maintenance management system for comparison with ongoing condition assessments and actual maintenance activities.

Condition Assessment and Performance Monitoring

Given that a transit agency's facilities' asset holdings can vary widely, no single performance monitoring and improvement approach applies to all agencies or all assets, but some basic program elements apply to most agencies. A comprehensive inspection and condition monitoring program may be put in place either as part of the facility management plan or as a separate document. The program should cover all facilities' assets and map to the facilities' asset inventory. Condition assessment and performance monitoring should result in the following activities:

- Prioritize and address immediate issues by completing reactive maintenance activities.
- Proactively identify cost-effective programs for any necessary preventive maintenance or rehabilitations.
- Assess the quality and effectiveness of maintenance activities.
- Collect condition and performance data for scenario evaluation and performance modeling and improvement.

Inspections are often the most cost-effective method to assess the condition of and identify issues related to facility structures including defects, deterioration, and damage. Facilities managers should have precise procedures for both higher-frequency routine inspections and more-detailed structural inspections. The protocols should be kept up-to-date as practices can evolve and new tools become available. Using handheld devices can increase the efficiency of inspection, allowing inspectors to access and enter data in the field. Inspection histories should be available digitally and allow for easy comparison of asset condition over time if possible. Third-party facility audits can provide quality control of an agency's practices, greater expertise for non-routine inspections (like an HVAC air balance test), and identify investments needs and quantify their benefits. Independent building condition assessments can help score and prioritize projects for capital planning. Third-party audits can validate an agency's operations and maintenance practices and may also identify easy opportunities for improved efficiency. **Table 3-2** provides examples of useful condition and performance metrics.

Table 3-2. Maintenance and Service Facilities Performance Metrics

Asset Class	Performance Metrics		Condition/Structural Assessment Metrics
Bus and Rail Vehicle Maintenance Facilities	▪ Availability (for example, percentage of elevator uptime) ▪ Safety (days without incident, number of worker's compensation claims) ▪ Compliance with facility preventive maintenance program ▪ Employee satisfaction	▪ On-time performance (indirectly) ▪ False alarms ▪ Energy efficiency, which can be measured by the billing costs of electricity, water, gas, and garbage ▪ Maintenance backlog	▪ Thermal imaging inspections ▪ Crack monitoring ▪ Moisture measurement – wood moisture content ▪ Radiographic measurement – internal cracking ▪ Concrete strength ▪ Indoor environmental conditions – temperature / humidity / air quality / relative pressure ▪ System diagnostic information – for HVAC, plumbing, security, backup systems, lights, uninterrupted power supply (UPS), switchboards (not very common), switchgear
Service Facilities	▪ Availability ▪ Safety (days without incident, number of worker's compensation claims) ▪ Compliance with facility preventive maintenance program or performance contract ▪ Employee satisfaction	▪ On-time performance (indirectly) ▪ Energy efficiency, which can be measured by the billing costs of electricity, water, gas, and garbage ▪ Maintenance backlog	

For facilities assets, an optimal capital maintenance and rehabilitation program focuses on timing projects based on observed asset condition. While minor planned maintenance follows a predetermined cycle, major maintenance and rehabilitation activities should be planned based on the inspection and condition history of the asset and the prescribed maintenance in the facilities management plan.

> Because there is significant variability in the optimal timing for standard maintenance procedures, condition monitoring is a critical asset management tool that yields high-value information.
>
> Data collection often focuses on asset condition or on tracking performance but does not necessarily help agencies identify root causes of performance issues or directly indicate appropriate response strategies. Transit agencies must not only ensure the performance monitoring program comprehensively covers all facilities' assets to a reasonable level of detail, but the agencies must also ensure there are effective processes in place to follow up on identified performance issues, identify root causes, and develop, implement, and monitor corrective actions. For instance, maintenance manuals can include guidance for diagnosing operational performance issues like high energy use levels.
>
> Facility performance monitoring can draw upon diverse sources. Data may be collected from building management systems, condition inspections, facility maintenance records, security personnel, and work space users in other departments. Effective business processes ensure these data are accurately recorded in a single database accessible throughout the organization.
>
> Quality control measures should be in place to verify maintenance activity effectiveness. Inspections must be completed carefully with instruments used properly and protocols followed dutifully. Quality control measures may include follow-alongs by experienced staff or third-party inspectors and comparison of data among inspectors. Transit agencies should especially verify the work quality of third-party contractors and record their performance over successive projects and contracts.

The asset monitoring approach should reflect the value of information and depend on the asset type and criticality. The cost of data collection varies dramatically according to the asset and the methodology. In-person inspections are relatively costly requiring special equipment and expertise, while automatic diagnostics have no marginal cost. As an example, poor luminescence has no direct costs but may have indirect costs related to safety and the deterioration of the customer experience. As a result, luminescence is typically checked infrequently at 2-year intervals despite the ease of testing with a handheld measurement device. Maintenance staff can perform many inspections as part of routine preventive maintenance activities (for example, monitoring for structural cracks or drainage issues). Handheld sensors can test for diverse issues including electrical leakage, roof leaks, and cold-air infiltration. Lately, agencies have employed thermal scanning to reveal water-logged insulation, openings in the exterior envelope of buildings, and broken seals in insulated glass. Such scanning allows an agency to identify issues before they become serious and to address them proactively. Agencies should periodically assess the value of data collected over various time horizons and adjust inspection procedures and schedules accordingly.

3.2.2 Stations

Not every transit agency is responsible for stations or other passenger facilities. Transit agencies with only bus and paratransit service often leave management of bus stops and bus transfer stations to local governments who are responsible for the public right-of-way. However, for some rail operators, passenger facilities represent one of their largest asset categories in terms of construction and replacement costs. Passenger facilities are also critical customer-facing assets, and good asset management practices for these facilities will help ensure customer safety and satisfaction. Passenger facility structures encompass diverse types, including below-grade fixed-guideway stations, stations on aerial guideway, and at-grade facilities with attached parking structures or commercial space.

Passenger facilities present the following asset management challenges that set them apart from maintenance and service facilities:

> The broken window theory suggests that monitoring and maintaining urban environments in a well-ordered condition may stop further vandalism and escalation into more serious crime.

- Customer preferences for safe and clean facilities have important consequences for facility design and operation that impact lifecycle management and costs.
- Passenger facilities are often geographically dispersed within a transit agency's service area and must be served by remote maintenance staff who are typically based at a central facility, whereas maintenance and service facilities often have maintenance staff and resources on-site.
- Unlike maintenance and service facilities, passenger facilities are often unmanned or nearly unmanned by transit agency staff. Passenger facilities usually do not host any workspaces.
- Passenger facilities interface with the transit right-of-way and often with public streets. Rail stations are often integral to the guideway, especially in the case of tunnels and aerial structures.
- Passenger facilities may host tenants, including commercial and retail space and services related to transit (car rental, bike share, bike stations, or customer service).

The following section relies on these points in its consideration of the design, preventive maintenance, and replacement of passenger facilities.

Design and Procurement Considerations

Both at the procurement stage and throughout a passenger facility's lifecycle, customer requirements should be a central design criterion to prioritize passenger facility features and to model and measure their expected performance. In general, passengers expect clean, safe facilities and prefer welcoming spaces with efficient access and egress.

Design elements to enhance facility safety can have implications for operating costs. For instance, more lighting requires additional maintenance. However, facilities that are designed for easy cleaning can positively affect cleanliness and cleaning costs through the life of a station. A simple measure like catch basins at tunnel entrances to catch debris before getting pulled into the tunnel can lead to significant cost savings over time.

As is the case for many areas of transit asset management, consultation and collaboration with space users, including the maintenance staff and transportation operations, can pay dividends in the development of the final design. The design and procurement processes should specifically address safety and comfort issues through the lens of maintainability.

A process for evaluating the net benefit of customer-focused improvements can help select features only for the most appropriate locations. It may be difficult to model the precise benefits directly attributable to such criteria—such as safety, passenger comfort, and cleanliness—but a transparent scoring process helps allocate limited resources. Transit agencies often deploy such improvements only to stations with certain levels of passenger use or where complaints or incidents have reached a critical threshold.

Performance modeling can help specify load requirements for critical equipment appropriately based on the likelihood of various load scenarios over the asset life and the resulting expected lifecycle costs. Distinguishing between environmental requirements and demand-linked requirements for passenger facilities can help transit agencies select appropriate, cost-effective equipment. Once a passenger facility is in operation, particular systems (for example, public restroom plumbing, elevators and escalators, and ticket vending machines) typically have high frequency maintenance needs because of high wear rates due to passenger use. The design team should take these use loads into account in specifying the systems. For instance, using heavy duty elevators or escalators that follow American Public Transportation Association (APTA) guidelines can improve their availability and reduce maintenance costs. These heavy duty assets are designed to withstand heavy use and abuse and intentional vandalism but have a much higher procurement cost. Conducting a reliability demonstration test for the first 30 to 60 days (following APTA recommendations for testing and startup of units) ensures that the system is installed and adjusted properly.

Transit agencies may find that the incorporation of so-called "smart elements" into the design of passenger facilities provides valuable data collection and remote management capabilities. Such technologies can help compensate for the limited agency staff available to manage often a high number of dispersed locations. One of the most common forms of remote monitoring is through closed-circuit surveillance cameras. Security system monitors should be able to quickly log instances of graffiti, flooding, or other obvious maintenance issues observed over the system for quick communication to facility maintenance staff. Another example of remote facility monitoring includes deploying sensors that diagnose light problems and trigger backup lighting, both alerting maintenance to the issue and addressing a potential hazard. While such systems require staff to monitor them and may need additional maintenance and troubleshooting, these systems can provide cost-effective operations coverage of passenger facilities, helping to identify issues and ensure system safety and availability.

Maintenance and Monitoring Considerations

An availability-based or otherwise performance-based contract may be an effective strategy for controlling station maintenance costs and maintenance performance. Contracting of maintenance is most appropriate when it is difficult for a transit agency to cost-effectively maintain the necessary expertise and resources in-house or when it is a commodity service that a transit agency can obtain more cheaply through procurement than by supplying. For instance, assets that require irregular or infrequent maintenance or that benefit from economies of scale unavailable within a transit agency may be appropriate targets for contracting. Escalators and elevators are a facility system class that frequently requires contractor support, and public agencies have often made use of availability-based contracts for elevator and escalator maintenance. Competitive bids for cleaning, landscape maintenance, and graffiti removal are common in the transit industry and represent commodity services where high numbers of vendors can offer acceptable quality and pricing. As an example where a vendor can be responsible for an asset's full lifecycle, some transit agencies employ advertising companies for the provision of bus shelters and waiting benches who then recoup their costs through managing the advertisement posters.

Transit agencies should periodically assess which elements of their operations are appropriate for contracting. In cases where it might be more cost effective for a contractor to execute an activity or function (or alternatively to bring a contracted activity in-house), an agency can perform further analysis to support a decision.

Risk assessment and risk management processes are important measures to have in place to cover third-party activities on transit properties. Enterprise activities—like cellular concessions and retail leases—can provide welcome income for transit agencies. Similarly, joint development can help improve the financial feasibility of projects and speed their delivery. However, transit agencies need to remain cognizant of the impacts such arrangements may have on asset management.

> A transit agency must ensure that each party clearly understands its responsibilities, that protocols are in place for accessing sensitive infrastructure (for instance, to maintain cellular infrastructure in the right-of-way), and that the transit agency is in a position to monitor another party's activities and enforce another party's asset management responsibilities.
>
> Fixed-guideway stations are adjacent to or integral to the right-of-way. If a transit agency does not own the right-of-way, it should ensure the station area is properly maintained. If a transit agency is not responsible for the maintenance of a passenger facility (for example, parking garage), it is important to develop maintenance requirements concurrently with the maintaining entity since there is a direct impact on the transit agency customers. It is important that responsibilities are clear and that departments coordinate capital maintenance, rehabilitation, and replacement. The facility management plan is an important guide for such coordination and should document such issues carefully.

Capital Rehabilitation and Replacement Considerations

Capital rehabilitation and replacement considerations for passenger facilities are broadly similar to those outlined under Section 3.2.1 – Bus and Rail Vehicle Maintenance Facilities and Service Facilities.

Condition Assessment and Performance Monitoring

Performance modeling for passenger facilities should reflect goals specific to passenger-facing assets. For instance, passenger facilities should emphasize safety and cleanliness to a greater degree. Passenger input from customer satisfaction surveys and a transit agency's customer service line are also important performance measures. Besides the typical factors of environment and age, passenger facilities' maintenance needs are also driven by revenue vehicle and passenger use; busy stations will need significantly more maintenance. **Table 3-3** outlines some of the performance metrics an agency can use to measure how well the facilities and stations are meeting their level-of-service requirements.

Table 3-3. Passenger Facilities' Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Passenger Facilities	▪ Thermal imaging inspections ▪ Crack monitoring ▪ Moisture measurement – wood moisture content ▪ Radiographic measurement – internal cracking ▪ Concrete strength ▪ Indoor environmental conditions – temperature / humidity / air quality / relative pressure ▪ System diagnostic information – for HVAC, plumbing, security, backup systems, lights, UPS, switchboards (not very common), switchgear	▪ Availability (for example, percentage of elevator uptime) ▪ Safety (criminal incidents, number of passenger injuries) ▪ Energy efficiency, which can be measured by the billing costs of electricity, water, gas, and garbage ▪ Lighting quality (luminescence) ▪ Compliance with facility preventive maintenance program ▪ Maintenance backlog ▪ Availability of seating in stations and shelters, as well as parking spaces in lots ▪ Customer satisfaction ▪ Cleanliness of stations and shelters ▪ Noise level ▪ Overcrowding

3.3 Industry Standards

The following list outlines any industry standards associated with the lifecycle of the facilities' and stations' asset classes:[18]

- **Facilities (All)**
  - International Facility Management Association (IFMA) Facility Management Standards: Includes standard practices applicable to comparison of areas with unknown measurements, space programming and forecasting of space requirements, classification of areas for internal cost accounting purposes, and comparison of space use between organizations.[19]
  - International Building Code publishes structural requirements, published by American Society of Civil Engineers (ASCE), and ASCE Minimum Design Load Specifications for Buildings and Other Structures: focuses on the regulations of design and installation of building systems, incorporating industry standards in material design and installation. The building code covers structural and safety provisions, interior finish requirements, roofs, seismic engineering, innovative construction technology, and occupancy classifications. [20]
  - American Concrete Institute, American Welding Society, and American Institute of Steel Construction standards: provides requirements for general structural design and also means for determining various loads: dead, live, soil, flood, wind, snow, rain, atmospheric, ice, and earthquake.[21]
  - Building codes and zoning codes, which vary by location.
  - Americans with Disabilities Act Standards for Transportation Facilities: Contains technical requirements for accessibility to sites, facilities, buildings, and elements by individuals with disabilities. These requirements are applicable during the design, construction, additions to, and alterations of sites, facilities, and buildings.[22]
  - American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) for Refrigeration Processes and the Design and Maintenance of Indoor Environments: Standards are meant to establish consensus for methods of test for use in commerce and performance criteria for use as facilitators to guide the industry. ASHRAE's five standards are as follows:[23]
    - Ventilation for Acceptable Indoor Air Quality: To improve indoor air quality in existing buildings by specifying minimum ventilation rates of new and existing buildings, and changes to existing buildings.
    - Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings: To improve indoor air quality in existing buildings by specifying minimum ventilation rates of new and existing low-rise residential buildings, and changes to existing low-rise residential buildings.
    - Energy Standard for Buildings Except Low-Rise Residential Buildings: To establish minimum energy efficiency requirements for buildings other than low-rise residential buildings. These requirements

[18] This supplement defines industry standards as requirements, standards, or guidelines that exist currently or are pending.

[19] Tools and resources for facility management: http://www.ifma.org/resources/tools-links/default.htm and facility management standards published by the IFMA: http://www.astm.org/search/site-search.html?query=E1836

[20] International Building Code, available for purchase: http://www.iccsafe.org/Store/Pages/Product.aspx?id=3000X12 and American Society of Civil Engineers/Structural Engineers Institute Minimum Design Load Specifications for Buildings and Other Structures

[21] American Concrete Institute Standards, available for purchase: http://www.asce.org/Product.aspx?id=2147487569 and http://www.concrete.org/PUBS/newpubs/318-05.htm
American Welding Society codes, available for purchase: http://pubs.aws.org/swps.php
American Institute of Steel Construction standards, available for purchase: http://www.aisc.org/content.aspx?id=2884

[22] Americans With Disabilities Act: http://www.access-board.gov/ada-aba/ada-standards-dot.cfm

[23] http://www.ashrae.org/standards-research--technology/standards--guidelines

pertain to the design, construction, operations and maintenance of these buildings and the utilization of on-site, renewable resources.

  - Energy-Efficient Design of Low-Rise Residential Buildings: To provide minimum design requirements for energy efficiency of low-rise residential buildings.
  - Standard for the Design of High-Performance Green Buildings: To provide minimum requirements for the siting, design, construction, and plan for operations of high-performance green buildings.

- Building Owners and Managers Association (BOMA) and International Facility Management Association (IFMA) general guidelines: The office standard provides a uniform basis for measuring rentable area using a building-wide approach to floor area measurement. It also provides a methodology for measuring occupant space and the space that benefits all occupants.[24]
- National Fire Protection Association (NFPA) Standards,[25] including but not limited to the following:
  - 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages[26]
  - 90A, Standard for the Installation of Air-Conditioning and Ventilating Systems[27]
  - 90B , Standard for the Installation of Warm Air Heating and Air-Conditioning Systems[28]
  - 130, Standard for Fixed Guideway Transit and Passenger Rail System[29]
  - 25, Standard for Inspection, Testing, and Maintenance of Water-based Fire Protection System[30]
  - 13, Standard for Installation of Sprinkler Systems[31]
- Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) Architectural Sheet Metal Manual: recommended practices for proper design and installation of custom-fabricated architectural sheet metal.[32]
- National Academy of Sciences Protecting Building Occupants and Operations from Biological and Chemical Airborne Threats: A Framework for Decision-Making: highlights considerations for designing and implementing buildings against biological and chemical threats.
- American Society of Plumbing Engineers (ASPE): Lists state plumbing codes and contacts.[33]

- **Stations**
  - American Public Transportation Association (APTA) Guidelines for Heavy Duty Elevators and Escalators: Guideline of technical provisions for the design and construction of heavy duty elevators, escalators, and moving walkways.[34]
  - National NFPA 88A Standard for Parking Structures: Standard covers construction, protection, and hazard controls in open and enclosed parking structures.[35]

---

24 BOMA's standards for office buildings: http://www.boma.org/MeasurementStandards/Pages/officestandard.aspx
25 http://www.nfpa.org/catalog/category.asp?category%5Fname=Codes+and+Standards&Page=1&src=catalog&order_src=B726&gclid=CNDglpjzmbACFUEGRQodPjybYg
26 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=30a
27 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=90A
28 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=90B
29 http://www.nfpa.org/assets/files/aboutthecodes/130/errata130-10-1.pdf
30 http://www.nfpa.org/aboutthecodes/aboutthecodes.asp?docnum=25&tab=docinfo
31 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=13
32 http://www.smacna.org/bookstore/index.cfm?fuseaction=search_results&keyword=Architectural Sheet Metal Manual, 7th Edition
33 http://aspe.org/StateListofCodes
34 http://www.aptastandards.com/Documents/TechnicalSpecifications/ElevatorsandEscalators/tabid/333/language/en-US/Default.aspx
35 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=88a&cookie%5Ftest=1

- National Parking Institute Parking Garage Maintenance Manual: Covers standard maintenance practices for parking structures.[36]
- National Parking Institute Guidelines for Parking Geometrics: Covers the design and construction of parking facilities including parking structures.[37]
- Washington State Department of Transportation Ferry Terminal Design Standards: Standards provide guidelines for the design of terminals to optimize capital and operating investments.[38]

[36] http://www.npapark.org/research/publications_description.php
[37] http://www.npapark.org/research/publications_description.php
[38] http://www.wsdot.wa.gov/NR/rdonlyres/41834A0B-DABC-48FA-9700-DF0298AA65B4/58497/AppendixBTerminalDesignStandards.pdf

Chapter 4

Guideways

4.1 Asset Class Overview

Guideway elements refer to the structural elements that allow for the movement of an agency's fixed-guideway vehicles. Guideway assets are broadly categorized into track elements, above-grade structures (bridges), below-grade structures (tunnels), and ancillary structures (for example, passenger and maintenance access and retaining walls). Failure to maintain minimum condition standards in any of these assets increases the risk of slow, unreliable, potentially unsafe, or inoperable service.

In most cases, a transit agency's rail service operates on an exclusive guideway, meaning the right-of-way is not shared with other traffic or services. The two main exceptions are 1) streetcar and light rail services, which use track embedded in the street and share right-of-way with general automobile or pedestrian traffic, and 2) commuter rail services, which may share right-of-way with freight rail or intercity passenger services. In the case of shared right-of-way, a transit agency may be responsible only for financial contributions or maintaining a subset of the assets.

The guideway asset category includes the following:

- **Track** refers to the guide structure directly under the wheels of the transit vehicle that distributes vehicle dynamic loads to its supporting infrastructure both above and below ground.

- **Bridges** refer to above-grade structures that span water, protected land, roadways, or other facilities. They are classified as fixed or moveable structures, including simply supported beam and slab, continuous slab, girder, segmental, and cable designs, depending on operational requirements.
- **Tunnels** refer to longitudinal underground structures that provide a conduit for rail or bus transportation. Boat sections are approaches to tunnels or depressed guideway that are similar to a tunnel but without a roof.
- **Ancillary Structures** refer to all other structures not detailed above that are required to physically support the safe and efficient operation of a transit system. These structures can include culverts, retaining walls, pedestrian walkways, utilities conduits, communications towers, light poles, safety fencing, and vehicular signals and signage.

Many guideway elements are required by federal, state, and local government regulations to have regular condition inspections and assessments since they are safety-critical. For most of these assets, there are preventive maintenance activities that can be performed to minimize risk of failures and to ensure the asset reaches (or even exceeds) its design life. Typically, transit agencies own their own guideway assets and are therefore responsible for all maintenance, rehabilitation, and replacement, but ownership and maintenance of guideway elements can vary. Some transit agencies are using alternative project delivery models like Design-Build-Operate-Maintain (DBOM) and Design-Build-Finance-Operate-Maintain (DBFOM) for system expansion projects. Also, design, construction, inspection, and various maintenance and renewal activities may be performed in-house or outsourced (to one or more contractors).

Asset inventories for guideways typically classify assets by rail mode (heavy, commuter, light, or other) and structure or track type (and often also include signal, communications, and traction-power electrification system assets). Track and track structural elements (like the substructure for at-grade track) are often the responsibility of a separate department from the tunnel and aerial guideway structures and, therefore, may have separate inventories, maintenance management systems, and business processes. If possible, these systems should be fully integrated with an agency's enterprise systems, and inventory data should be tracked in a single agencywide database. All of the asset classes included in the guideway elements category are organized in a proposed asset hierarchy in **Table 4-1**.

North County Transit District (NCTD) serves northern San Diego County in California with 144 buses, 7 commuter trains, and 12 light rail DMUs. The agency is responsible for 41 miles of commuter rail right of way and 22 miles of light rail right of way. NCTD's FY2013 2017 Capital Improvement Plan dedicates 55 percent of capital funds to right of way improvements compared to 29 percent to revenue vehicles in order to address the operational and state of good repair needs of its fixed guideway system.

Track elements require significant maintenance and investment over time to maintain performance and allow revenue vehicles to move at authorized speeds with minimal vehicle wear and maximum comfort. Aerial guideway structures and tunnels are costly assets and represent a high share of guideway lifecycle costs. Regardless, the assets should be evaluated relative to their remaining life to avoid the failure of the components in a timeframe that would not allow for repair or replacement. For agencies with high bridge and tunnel mileage, these assets may represent the greatest financial need of the whole transit system. When long life assets require rehabilitation or replacement, it can concentrate large financial needs across short timeframes. Transit agencies with significant bridge and tunnel guideway assets need a long-term financial planning horizon to ensure they can plan and prepare for major rehabilitation projects and carefully maintain the system.

Table 4-1. Guideway Elements Asset Classes' Proposed Asset Hierarchy

Asset Class	Sub Assets		Related Assets	
Track	▪ Ballasted – Rail – Fastening system – Crossties – Ballast and sub-ballast – Subgrade ▪ Direct fixation track – Rail – Rail fasteners – Plinth	▪ Embedded track – Rail – Resilient membrane – Track slab – Rail fasteners ▪ Tie block track ▪ Open deck aerial track ▪ Turnouts ▪ Special track work	▪ Joint bars ▪ Frogs ▪ Switch points ▪ Switch machines ▪ Insulated joints ▪ Spikes	▪ Tie plates ▪ Third-rail insulators ▪ At-grade crossing ▪ Rail anchors ▪ Specialty components
Bridges Structures	▪ Steel Bridges – Viaducts – Steel trestles – Truss Spans – Grider spans ▪ Timber Trestles – Caps – Stringers	▪ Concrete Bridges – Concrete Griders – Slab Bridges – Arches – Concrete Trstles ▪ Moveable Bridges – Swing – Vertical lift – Bascule	▪ Abutments ▪ Expansion joints ▪ Rail attachments ▪ Bearings and support pads ▪ Diaphragms and cross bracing ▪ Cable support systems suspension bridges ▪ Pylons ▪ Anchorage systems	▪ Bridge pier caps ▪ Concrete pavement ▪ Columns ▪ Piers ▪ Structural support connections ▪ Foundations ▪ Navigational protection (fender) systems
Tunnels Structures	▪ Tunnel structure ▪ Ventilation shafts ▪ Fire/life safety ▪ Fire standpipe ▪ Ventilation equipment	▪ HVAC ▪ Tunnel systems ▪ Special tunnel structures ▪ Drainage	▪ Track support systems(floating slabs) ▪ Masonry elements ▪ Concrete elements ▪ Framing steel ▪ Support columns ▪ Tunnel lighting	▪ Power distribution systems ▪ Intrusion and security systems ▪ Cross passages ▪ Emergency egresses ▪ Fire detection systems
Ancillary Structures	▪ Under-track culverts and crossings ▪ Systemwide cable troughs and/or duct banks ▪ Under-track/over-track pedestrian walkway structures ▪ Retaining walls	▪ Barriers and noise protection walls ▪ Information and sign structures ▪ Fender systems ▪ Utility hangers	▪ Headwalls ▪ Handicap access facilities ▪ Jersey barriers ▪ Motorman sanitary facilities ▪ Columns ▪ Beams	▪ Trusses ▪ Connections ▪ Piles ▪ Planks ▪ Foundations

4.2 Lifecycle Management Practices

The longevity of guideway structures means that there may be a relatively high level of financial uncertainty and risk over the course of the asset useful life. Guideway assets typically represent some of the largest capital assets of a transit agency, and without timely and effective maintenance, these assets may require additional or more costly rehabilitations to reach their full design life. The guideway asset owner should specify the requirements associated with the asset lifecycles—including design requirements, preventive maintenance activities, expected rehabilitation needs, and lifecycle costs—and incorporate this information into the lifecycle management plans for track, tunnels, and bridges. In addition, transit agencies should be prepared to provide robust ongoing engineering support to modify the maintenance approach based on ongoing condition assessments and address unforeseen technical issues as they arise. **Table 4-2** lists some of the factors influencing guideway asset lifecycle management.

Table 4-2. Circumstances Potentially Affecting Cost and Performance of Guideway Elements

Lifecycle Categories	Circumstances	
Design and Construction Decisions	▪ Durability/Quality of materials ▪ Ventilation requirements ▪ Drainage quality	▪ Required clearances ▪ Accessibility
Operating Approaches	▪ Hours of operation (off-line time) ▪ Track usage for maintenance	▪ Vehicle speed and traffic level ▪ Quality of train operator
Maintenance Practices	▪ Level/quality of routine/preventive maintenance ▪ Use of performance-based maintenance approaches ▪ Level of cleanliness	▪ Proper drainage maintenance ▪ Inspection procedures and equipment ▪ Maintenance equipment ▪ Quality/experience of workforce
Miscellaneous	▪ Vandalism ▪ Vibration ▪ Natural environment (for example, earthquakes, tornados, ice, ground water, rain, flooding and excessive heat caused by direct exposure to the sun, seasonal changes [cold and hot weather], abusive use and poor or lack of routine maintenance from water leakage and corrosion)	

The following sections describe the lifecycle activities and considerations that are specific to guideway elements for each of the asset classes.

4.2.1 Track

Track wear and deterioration is closely tied to a number of use-related factors as well as age and environmental variables. For a particular track segment, track wear factors include the following:

- Those related to vehicles and operation (vehicle weight, total traffic levels, vehicle speed, consist length, and the braking and acceleration rates)
- Factors related to track geometry and construction (drainage, the segment slope, the turn radius for curve segments, the track and rail type, and the ballast and subgrade or direct fixation construction)
- Environmental factors (average daily high and low temperatures, average humidity and rainfall, and exposed versus tunnel track)
- Past maintenance treatments (including their quality and timing)

Such complexity means that any two rail systems are not necessarily directly comparable even if, for example, they are both heavy rail systems. The following outlines lifecycle management considerations for the design, preventive maintenance, rehabilitation, and condition monitoring of track assets.

Design and Procurement Considerations

An agency's accumulated track maintenance engineering knowledge provides invaluable support for lifecycle cost analysis of track construction and renewal. Most transit rail systems have a wide variety of track construction choices, whether for commuter, heavy, or light rail. Lifecycle cost analysis is a valuable tool to understand long-term direct costs (including construction, maintenance, and rehabilitation) and indirect costs (such as track availability and reliability). Likewise, many systems include diverse track types and construction methods over various segments. To the extent the maintenance program can track performance of various track options, this information serves as a valuable input to the lifecycle cost analysis.

The track maintenance program may also support design by identifying particular performance issues that cannot be cost-effectively addressed through maintenance but can be addressed through improved design when the asset is rehabilitated or replaced. As an example, some transit agencies have found that, in some cases, using harder steel in the wheel contact area delays the onset and reduces the severity of corrugation—a common rail wear pattern that increases friction and noise. Thanks to technological advances, the price differential that rail producers charge for head-hardened rail relative to standard rail has recently fallen to about 10 percent. Transit buyers can realize a rapid return on the higher initial costs because of longer rail life and decreased costs for corrugation mitigation. Staff track engineers can then validate these savings by tracking and comparing the head-hardened rail against a test segment. The same can apply to rail life extension through friction control applications and rail grinding.

More than for other asset classes, track maintenance programs can rely on testing to verify their approach and to identify performance improvement opportunities. Staff track engineers are well positioned to develop and test such performance improvement strategies while maintaining safety. The division must also have effective processes to implement performance improvement measures. The adjustment of maintenance and operation practices can benefit from the support of a proactive and collaborative agency culture that takes ownership of improvement proposals.

Engineering or construction defects are significant determinants of track rehabilitation and replacement. Issues originating in the design and construction of the rail drainage can cause long-term chronic maintenance problems. Third-party oversight of contractors can improve quality assurance and quality control (QA/QC) in the construction phase. Effective design review and modeling are also critical QA/QC processes with which to manage lifecycle costs. As an example, abrupt transitions in track construction type in mid- to higher-speed tracks, such as at bridge approaches, can cause high dynamic loads and lead to rapid condition deterioration and a high level of maintenance. Such transitions are especially damaging in environments such as commuter rail systems, which have both high axle loads and high speeds. Transition agencies can address these transitions points in the initial design with careful engineering, including measures such as approach slabs at ballast-to-structure interfaces, elastomer pads on concrete ties, or localized increases or decreases in fastener spacing. If the original design is ineffective, it may be possible to retrofit the track section, but retrofits are not necessarily cost effective relative to the maintenance savings. A procurement approach emphasizing the minimization of the annualized total lifecycle cost and taking into account major maintenance and rehabilitation costs can help support such an approach.

Maintenance and Monitoring Considerations

Robust data collection and performance measurement and modeling are important strategies to tackle one of the primary challenges track maintenance challenges: friction management. Friction is a major determinant of track wear and rail maintenance costs and is a focus of many rail maintenance activities.

> Many transit agencies recognize that a proactive grinding program effectively controls the rate of corrugation formation. Controlling corrugation minimizes noise, smoothes the ride, and reduces wear and impact forces on track structure and the rail vehicle.
>
> Rail grinding can also serve to remove rail head surface cracks, which can grow into detectable flaws and, eventually, broken rails. Addressing rail head surface cracks is an important consideration in areas where commuter rail operations might share track with freight railroads.
>
> Another friction management approach in use by freight railroads and potentially applicable to busy heavy and commuter systems is track lubrication. Controlling friction on the top of the inside rail on curves can also quiet wheel squeal noise and greatly reduce gauge-widening forces on the rail and fasteners on sharp curves. Typically, grease is applied to the gauge side of the rail head while proprietary formulations known as "friction modifiers" are applied to the top of rail.
>
> Some transit operating personnel oppose the use of rail lubricants because of concerns with sliding wheels or contamination of the right-of-way; however, modern lubricating equipment allows precise control of the application rate so that adverse effects that result from too much lubricant are minimized.

To date, none of these measures have yet been tested broadly enough to establish standard practices. To the extent a transit agency can collect its own high-quality data from onboard vehicle sensors, track inspection and measurement, and maintain a high quality rail asset inventory, it is possible to resolve many issues within an agency's specific operating environment. Effective engineering relies on well-targeted data collection and careful control of variables in testing and analysis. Rail crack inspections and wayside sensors can be expensive measures, but track maintenance requires substantial resources, and so high-quality data can lead to substantial savings. In especially busy systems, transit agencies have little off-line time in which to perform track maintenance. Efficiently targeting maintenance and inspection activities and carefully evaluating maintenance procedure effectiveness has proven to be an effective cost control strategy.

> Manufacturers of electric rail welding equipment have perfected techniques to mount their equipment on hi rail trucks. These trucks are able to drive on the rails to each joint in the rail strings and join the strings using electric welds rather than thermite welds. The electric welds are stronger and of a more consistent quality than thermite welds. Depending on quantities ordered, electrica rail weldoing equipment may also be cheaper.

Track maintenance departments should ensure they are taking advantage of industry innovation in lifecycle management practices by supporting key staff members' ongoing technical knowledge development. Participation in trade groups, knowledge sharing with peer agencies, cooperation with academic researchers, outreach to diverse vendors regarding critical technical challenges, and the selection of high quality consultants can all help bring advanced technical knowledge and innovative asset management practices into an agency. Staying up-to-date on recent research is one example of how transit agencies can leverage broader industry experience. For example, rail-tie decay is an issue for many transit agencies in more humid regions of the United States, and recent research by Mississippi State University has shown that ties treated with a combination of creosote and borate solutions can substantially increase decay resistance over ties treated with creosote only. In service environments where tie life is dictated by decay rather than mechanical wear, borate-creosote treatment can extend tie life. The dual treatment also provides an environmental benefit in that the amount of creosote needed per tie is greatly reduced. Research projects often cover issues that an agency does not have sufficient resources to address, so staying up-to-date on relevant research can help transit agencies identify valuable new asset management strategies at an earlier stage. Transit agencies vary in their adoption of new, conservative or aggressive maintenance approaches, but all agencies can benefit from a clear engineering approach to identify opportunities, evaluate them, and track effectiveness after adoption.

There can be significant performance improvement when an agency's track maintenance and vehicle maintenance departments collaborate to address asset management. In some cases, track maintenance strategies can have an impact on vehicle performance and vice versa. For example, a rigorous wheel maintenance program can reduce maintenance costs for both track and vehicles. Under hard braking conditions on slippery rails, some wheels may lock up, resulting in the wheels sliding on the rails and wearing a flat spot into the wheel treads. These flat spots, in turn, create impacts with each wheel rotation that can be double or triple the dynamic loads ordinarily exerted on the rail and track structure. Flat spots can be removed by truing the wheel to a like-new profile. Severely worn wheels can also adversely affect the steering of the wheel set, causing high lateral forces that result in accelerated wear and (at the most extreme conditions) potential derailment. The validation of a wheel-grinding program's effectiveness for reducing track maintenance costs necessitates tracking both vehicle and track performance and costs, controlling, if possible, for other variables. There must be a process to prioritize such issues for cooperative engineering and approve and implement proposed tests and improvements. More generally, it is important that each department accounts for cost implications to other departments and focuses on agencywide goals.

As with other asset classes, it is critical to carefully prioritize track maintenance activities. For guideway, a fully reactive maintenance approach is unacceptable from a safety and cost standpoint because neglecting preventive maintenance can accelerate asset decay and lead to outsized costs and risks. For instance, properly functioning drainage is the single most important consideration in cost-effective maintenance of track. In ballasted track, maintaining a dry sub-ballast and substructure provides a higher-strength track structure that retains good ride quality much longer than if the subgrade is wet. Channeling of water away from the track has an additional advantage of reducing stray current since a damp track structure has much lower track-to-earth resistance. As a chronic maintenance issue, drainage problems may not receive priority on any given day relative to acute maintenance issues. However, sustained neglect of drainage maintenance can lead to outsized corrective costs. A maintenance prioritization process helps agencies avoid following into such a trap where their focus on acute issues leads to ineffective risk management and to the abandonment of lifecycle-based asset management.

Capital Rehabilitation and Replacement Considerations

In general, a right-of-way maintenance program includes two key track-related rehabilitation elements when track surfacing and spot tie renewal will not maintain reliable performance and safe operation: (1) rail and tie (if applicable) replacement, which occurs regularly to replace worn ties and rail and decaying fasteners and to correct rail alignment, and (2) structural track work (such as ballast cleaning, undercutting, and full excavation) to correct the track profile and to clean, regrade, and renew the aggregate foundation for stability and proper drainage. For embedded track in a shared right-of-way, rail replacement and track structural work often form a single rehabilitation project. Direct fixation track work can be less intensive. Transit agencies both contract and directly perform track replacement.

Careful analysis of past maintenance and rehabilitation experience and forecasts of future needs can help transit agencies plan appropriate renewal projects and balance between contracted and directly performed track work. Typically, in-house track replacement programs try to perform continuous replacement to optimize their work capacity and level out their work force. An optimized inspection program and an accurate and detailed track inventory can prioritize track replacement and optimize track useful life and lifecycle costs. Narrow timeframes for completing track work can greatly increase the complexity and intensity of projects. More intensive rehabilitation and replacement projects use contractors to augment their workforce. Track replacement or rehabilitation projects are scheduled to obtain as much track occupancy as allowable to perform the work. Therefore, projects are normally performed during off-peak hours—as night work unless prohibited by local ordinances or union regulations—and on weekends. With tunnel right-of-way and right-of-way in non-residential areas, transit agencies can avoid service impacts through night work. Since short work hours and nighttime work raise construction costs, coordinating with operations well in advance to plan rehabilitation outage periods may help reduce costs and minimize service disruptions.

Condition Assessment and Performance Monitoring

Track inspections are a critical quality control measure to assess both the quality and effectiveness of maintenance procedures, as well as to comply with federal regulations for jurisdictions under FRA jurisdiction. Transit operators should make the most of advances in track inspection and maintenance technology to drive performance improvement of their maintenance operations. Electronic inspection and measuring systems now handle tasks as diverse as finding rail defects, measuring track geometry, quantifying rail wear, testing track strength, ground-penetrating radar of subgrade conditions, calculating rail neutral temperature, and assessing timber tie conditions. These systems can provide automatic reporting of defect locations and can store condition information to compare conditions year to year and help transit agencies more cost-effectively manage asset renewal.

Track inspections and measurements take three forms:

- Vehicle-based inspections, which use onboard sensors on a maintenance vehicle to gather information. Ultrasonic testing is an example of vehicle-based field measurement. Ultrasonic testing of rail in track is conducted to identify and locate internal defects before these defects grow under repeated load cycles into potential rail breaks. Most rail-transit properties conduct rail testing at levels appropriate to their service environments. Transit agencies under FRA jurisdiction are required to test rail ultrasonically in Track Classes 3 and higher at least once a year. High tonnage routes require more frequent testing.

  Electronic track geometry testing has become a standard for both passenger and freight rail operators and is another example of a vehicle-based inspection technique. Track geometry is tested by rail vehicles or highway-rail vehicles outfitted with instrumentation to measure parameters such as gauge, cross-level, alignment, profile, and lateral track strength under load. These readings are especially useful for rail maintenance planning, since comparing rail geometry year-to-year permits monitoring of degradation rates and prediction of required maintenance cycles. Many railroads rely on a track geometry index, which weighs combined multiple metrics of track geometry into a weighted average that describes the overall condition of a stretch of track. Another means of comparison is simply measuring the total number of track geometry deviations from a recognized standard each year.

- Wayside sensors, which gather measurements. As an example of wayside data collection, the nation's freight railroads, Amtrak, and some transit agencies have installed telemetric devices on their main tracks that measure impacts from passing wheel loads. From these loads the devices can identify flat wheels on passing trains and alert operating personnel that certain vehicles need to be sent to the shop for wheel maintenance.

Currently, the results from these programs are largely proprietary; however, as the technology continues to develop, it may lead to wider use on transit systems, which in some cases have pervasive problems with flat wheels.

- In-person inspections using handheld device or visual inspection. Track inspection by hi-rail or walking is an example of in-person visual inspection, although higher train frequencies and the resultant capacity limitations, hi-rail inspections are becoming less frequent on transit properties. In addition to the visual inspection the inspector should be required to have the appropriate hand tools to measure cross-level, gauge, and alignment.

Beyond determining what data must be measured or collected and how to do that, there must also be a system in place to record information and evaluate historical data. Location-based data from in-person and vehicle-based inspections should be matched to track asset inventory data, usually divided into track segments identified by mileposts. Together with location-based maintenance data, the location-based condition data are the foundation of a performance-based track maintenance program. It is recommended that the data be "hung" on a track chart with the appropriate levels of asset inventory. Wayside sensors contribute by helping the engineering staff improve their modeling of the physical processes driving track wear. Transit agencies can use inspection data to introduce risk-based scoring into their prioritization process to better allocate maintenance resources. **Table 4-3** provides examples of track condition and performance measures. When an agency is an owner of infrastructure maintained by others, it is important to have an asset inventory with an up-to-date condition database to ensure the various components are being maintained during the contract period.

Table 4-3. Track Elements Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Track	▪ Component life ▪ Track geometry index ▪ Rail defects per mile ▪ Rail head section loss ▪ Lateral accelerations	▪ Availability ▪ Total mileage or percentage of track with speed restrictions / current minimum travel time versus designed minimum travel time ▪ Noise levels ▪ Rail wear rate by track section ▪ Frequency of recurring perturbation by location

A risk-based inspection approach to track management can support improved system safety. For example, turnouts are key safety points that can undergo more rapid wear from consistent acceleration and braking and frequent switch use, and therefore, need frequent inspection and adjustment. FRA-regulated transit properties are required to intensively inspect each mainline turnout monthly, with visual inspection performed on the more frequent track inspection cycle. This, generally, is the minimum standard inspection interval even on systems not subject to the FRA regulations. Factors affecting turnout life include traffic levels, speeds, percentage of diverging movements, track surface, drainage, turnout geometry, and the type and quality of turnout materials. Understanding how these factors affect track wear and condition helps allocate scarce maintenance resources where they are most needed.

4.2.2 Bridges

This section outlines lifecycle management considerations for the design, construction, preventive maintenance, rehabilitation, and replacement of bridge and aerial guideway structures. Broadly, bridges consist of a superstructure, substructure, foundation, and other non-structural components and systems. Bridges are defined by their span distance, load bearing capacity, and design and construction type. The specific asset management approach for an individual bridge will vary according to these factors. The following focuses on general principles and approaches related to transit bridge asset management.

Design and Procurement Considerations

When there are oversights, poor decisions, or mistakes during a bridge's design and construction, these directly translate into higher lifecycle costs through more intensive maintenance, rehabilitations, or retrofits. Quality assessment and quality control measures like design review, materials testing, and construction inspections are critical risk management measures to identify issues potentially impacting bridge performance at an early stage when corrective measures are the least costly. The cost of addressing design and construction flaws typically increases as time elapses and project progress makes correction more difficult.

> The design and construction of bridges requires cooperation among people with diverse expertise from materials engineering to ocean engineering. For the design phase, the project staff should include reviews by senior engineers of the interaction between materials, structural, geotechnical, drainage, hydraulic, moveable (electrical and mechanical), and scour (foundation erosion) engineering to check design requirements and specifications with applicable codes, models, and standards and with forecast levels of use through the full design life.
>
> The QA/QC process should also include an assessment of the design’s constructability and maintainability, including a lifecycle cost model to improve the cost-effectiveness, durability, and serviceability of structures.
>
> Construction quality control is important since elements not built to specification can necessitate costly correction beyond the project budget. If not detected by quality inspections, construction flaws may go undetected for years after project completion. Construction quality control includes materials testing and acceptance, and inspections to verify a contractor’s adherence to a plan’s details and specifications.
>
> For rehabilitation or replacement projects where the bridge remains in service, QA/QC is a critical safety measure.

Transit agencies have growing options to incorporate advanced management technologies into bridge design to support improvement management of bridge structures. Transit agencies can apply structural health instrumentation either in the construction phase or after to meet specific data needs. Increasingly, designers are incorporating sensors into plans for continuous data collection at inaccessible points. Such data collection can improve the accuracy of condition assessments and better track unseen wear and deterioration of the structures, helping transit agencies better manage risk and allocate maintenance and investment resources. Agency staff responsible for bridge maintenance should have a careful understanding of such systems and how they should be incorporated in condition assessments and maintenance decision making.

Maintenance and Monitoring Considerations

Agencies with complex bridge structures or high numbers of bridges should also have a general bridge management program in place to ensure they meet regulatory requirements and properly maintain these assets over the long term. Transit agencies can have diverse bridge asset holdings. Many heavy rail agencies often have miles of ageing viaduct. Commuter rail operations may have high numbers of short-span bridges of similar construction and only have a small number of complex bridge structures. A light-rail system may have only a handful of relatively short-span bridges. Complex bridges should have a bridge maintenance plan in place to cover inspection protocols, routine maintenance, and issues specific to the bridge. For example, an agency may have an ageing moveable bridge, which requires custom fabrication of replacement parts. Simple structures can follow a standard maintenance and inspection plan appropriate to their design and location.

Basic cyclical maintenance includes cleaning and painting, deck resealing, patching and repair, crack repair, bearing lubrication, and joint replacement and repair. Preventive maintenance measures include activities like various kinds of waterproofing, cathodic protection, bearing lubrication, and scour countermeasures. Crack repair, joint repair and replacement, and deck patching are considered reactive maintenance. The database of maintenance records is most useful for evaluating the effectiveness of these measures if it is location based. Agencies should try to define bridge subelements precisely to track issues over time.

A well-defined and implemented maintenance and preservation plan must include a condition inspection and evaluation plan that will identify, eliminate, or mitigate the causes of structural deterioration. In general, deterioration of structures is related to environmental, material, or load-related conditions. The effects of these are significantly influenced by design and construction factors.

A bridge can reach its design life only if maintained appropriately. Transit agencies must conduct minor repairs, as needed (based on routine inspections), which typically add no structural strength to the elements (for example, joint sealant reapplication, repair of minor concrete spalls, steel coating repairs, surface cleaning and vegetation control, and corrosion arresting actions).

Corrosion mitigation in particular is a focus of bridge maintenance programs. Regular bridge cleanings of the lower chords, bearings, and caps can prevent corrosion and are critical in marine environments. If a ballast deck bridge requires track and ballast removal because of deterioration, it is recommended that the deck be sealed and the drainage system be in working order. Deck sealing prevents water penetration and can include the following treatments: seal cracks, seal with In Deck or asphalt chip seal. Structural joints are a critical maintenance target because of higher corrosion vulnerability and their significance to structural integrity, and treatments include hot pour, silicone seal, and polytite seal.

A properly designed and constructed bridge structure will respond adequately to expected conditions within the expected design service and beyond only if properly maintained and preserved.

Structures are designed and constructed to handle known or expected environmental exposure and loads during the planned service life if materials are selected accordingly.

Material defects or improper design or construction can significantly affect the expected behavior of a structure.

Structures subjected to loads in excess of design loads will experience unaccounted effects that will negatively affect its service level and shorten its service life. Load increases can occur due to unexpected load levels such as exposure to transportation load increases, seismic, accidents or other natural events.

Capital Rehabilitation and Replacement Considerations

Bridge rehabilitation usually involves major structural repairs that maintain or add structural strength to the elements and structure. Bridge rehabilitation also addresses chronic maintenance issues, natural or use-related structural deterioration that has exceeded acceptable thresholds determined by the agency, deterioration related to deferred maintenance, damage caused by a particular event, or the correction of design or construction defects or deficiencies. These repairs are typically localized (for example, restore steel and concrete in reinforced concrete structures, replace post-tensioning anchorage protection systems, replace or repair steel brace elements, or partially replace deck surface). Such repairs are required to meet the design or expected service life of the structure and may help to extend the structure's service life. Examples of rehabilitation activities may include repairing or replacing decks (including conversion from open deck to ballast deck bridges), foundations, joints, approaches, or other structural components (such as cables, slope or scour protection, bearings, beams, and comprehensive corrosion mitigation). Bridge rehabilitations may also improve functional serviceability supporting higher load capacity, improved transit operations, or adding widening to accommodate additional track.

Bridge rehabilitations tend to be major investments with a wide range of options in most cases, so the planning phase is critical for understanding how the rehabilitation supports a bridge's lifecycle management. In planning a rehabilitation project, transit agencies should consider the change in the bridge's sufficiency rating (the measure of its overall serviceability and condition), its capacity to meet existing and forecast traffic volumes and loads, the bridge's current and forecast condition, and an economic analysis of the rehabilitation's impact on the bridges' total lifecycle cost. The rehabilitation design should also review maintainability and seek to improve it. Agencies with historic bridges must also give special consideration to such heritage assets. Transit agencies can draw such information from past inspections, operations data, review of the bridge design, and planning documentation.

Bridges are typically critical points within transit rail systems, and their availability during rehabilitation is critical for system operation. Maintaining a bridge's availability comprises much of the cost of many bridge rehabilitation projects. Transit agencies must balance the direct costs of special construction measures to maintain service during construction with the indirect costs to passengers and the local economy of service disruptions (as well as the direct cost of lower fare revenue). By their nature, bridge rehabilitation and replacement projects have the potential to either affect service or incur additional costs. In response, contractors have developed a variety of techniques to minimize the impact of construction on track availability, minimizing the need to bus passengers and other mitigation measures. These strategies generally focus on either completing key construction steps during out-of-service periods or constructing in-line or off-line temporary structures. Given the extra costs of rehabilitation, transit agencies should make reasonable tradeoffs between bridge availability and construction costs. In some cases, the agency may be able to test the rehabilitation approach to ensure it is appropriate.

As mentioned in Section 4.2.1 – Track**, bridge approaches are often tracks sections requiring high levels of maintenance.** Because of imperfect engineering and dynamic conditions, these transition zones are frequently susceptible to rapid development of track irregularities, which require costly ongoing maintenance. Bridge rehabilitations can be an opportunity to address problematic approaches, improve maintainability and long-term costs, and address safety issues to permit higher speeds.

Condition Assessment and Performance Monitoring

Transit rail systems use bridge designs functionally similar to street, highway, and freight railroad designs, and have benefitted from adopting bridge management practices from these industries. In general, state and local government transportation agencies adhere to the Federal Highway Administration (FHWA)-established requirements and guidelines for the inspection of bridges, and some have implemented more stringent inspection and maintenance requirements. The FHWA inspection-frequency requirements for above-water and underwater bridge inspections vary by bridge type; however, considering that foundation scour (erosion) is the leading cause of bridge failures in the U.S., many states require biennial routine inspections (including scour) for all bridges and annual inspections for fractural critical structural elements. The American Public Transportation Association also publishes standards for fixed structures inspection and maintenance (see end of section).

Monitoring the condition of bridge components helps to identify corrosion, cracking, structural section loss, seismic weakness or impacts, foundation issues, and scouring, and helps to facilitate deterioration modeling.

After a bridge's construction, reconstruction, or major rehabilitation project, the first step is a baseline inspection to establish initial conditions. The baseline inspection is thorough, and the initial condition includes documentation of any initial wear or defects, especially on key structural elements. The baseline inspection establishes the bridge's initial condition score, which is typically a composite score indicating the bridge's level of service and risk level.

The initial routine maintenance and inspection frequency should be based on general industry experience for the bridge type. In general, complex bridge designs require a shorter initial inspection interval. Subsequent routine inspections at pre-established inspection frequencies document the actual condition of the structure as it ages and quantifies the level or growth of deficiencies with varying levels of documentation.

Criteria should be established to determine the level and frequency that bridges should be inspected, including age, traffic characteristics, and known deficiencies. With each subsequent inspection, past bridge performance should increasingly determine the interval until the next inspection; for instance, increasing deterioration rates based on the inspection history may necessitate a higher inspection frequency and a more intensive maintenance program.

Table 4-4 provides examples of common bridge condition and performance measures.

Table 4-4. Bridge Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Bridges / Aerial Structures	▪ Bridge condition score ▪ Maintenance backlog ▪ Level of chloride contamination ▪ Freeze-thaw test ▪ Half-cell analysis ▪ Deck deterioration (cracking / spalling / delamination) ▪ Paint condition ▪ Joint condition ▪ Foundation / substructure condition	▪ Percentage of bridge assets in each priority area with unacceptable condition rating (can be weighted by span length) ▪ Number of bridges or span distance by condition rating ▪ Maintenance backlog by priority score ▪ Number of maintenance issues overdue for followup ▪ Load capacity ▪ Cleanliness

Deterioration modeling based both on the inspection history and historical data from the agency's comparable bridge assets can support scenario analysis to understand the total lifecycle cost implications of various maintenance and investment options. Some agencies use the American Association of State Highway and Transportation Officials (AASHTO) Pontis software, an element-level condition inspection and assessment tool that is used to numerically rate the condition of core elements, document and quantify condition deficiencies, and model investment needs at both the individual bridge and network levels. As bridge maintenance

A state highway department manages identified bridge maintenance issues by assigning a priority score as issues are logged. Priority 1 maintenance issues must be addressed within 60 days, Priority 2 issues within 180 days, Priority 3 issues within one year, and Priority 4 issues by the next inspection. This system helps the agency manage its workload while prioritizing maintenance issues to maximize performance and minimize risk.

issues are identified, transit agencies often must perform some level of triage in addressing them. For instance, the Massachusetts Bay Transportation Authority has customized the agency's software for rail and other transit bridges and can use it to prioritize bridges for rehabilitation and reconstruction.

Some agencies are instrumenting certain bridges to monitor structural health. The value of a structural health monitoring plan varies with the complexity of the structure and its service and replacement value. Transit agency staff should take into consideration the value of such information in any major deployment of a structural health monitoring system, which will be highest for complex, higher-risk structures. There are many instrumentation systems available to identify and monitor the condition of structures, from old-reliable strain gauges to state-of-the-art acoustic and wireless monitoring sensors. Likewise, advancements in global positioning systems (GPS) and other measuring tools facilitate the capture of extremely sensitive measurements and movements that can alert maintenance staff to changes in the condition of a structure and facilitate the calibration of structural behavior and deterioration models. Such instrumentation can be installed late in a structure's life or as part of the original construction.

4.2.3 Tunnels

Tunnels are complex long-life assets, often of unique construction, which many times have their own facility-specific lifecycle management plan and maintenance requirements that also address tunnel safety. This section discusses in general the lifecycle management considerations, including the design, maintenance, rehabilitation, and management and monitoring of tunnels, U sections, cross passages, and shafts and emergency egress facilities. Tunnels serve the dual purpose of providing a supporting structure for track and retaining earth to maintain the below-grade right-of-way. Tunnels not only hold the track, but also any traction power systems, communications, train control equipment, and tunnel utilities like ventilation, lighting, and water pumps. Tunnels face several key challenges due to the placement of structures below grade. Tunnels are defined by their length, depth, circumference, local geology, and the construction type. Tunnel shapes vary depending on the construction type. Broadly, the tunnel structure may be unlined rock, lined and reinforced rock, or a fully artificial structure. Key tunnel features include the invert slab, which the track rests upon, and the safety walk for access and emergency egress.

Water leakage is an important driver of tunnel asset management practices because of its role in structural deterioration. It can corrode concrete, in some cases, as well as structural steel. For systems with electric traction power in particular, addressing tunnel leakage and drainage is critical to maintain system operation and can mitigate stray current and structural wear from electrical leakage. Groundwater can be saline, which increases its corrosive effects. Access for structural maintenance and rehabilitation is also problematic and an important design and operational consideration. Other causes of tunnel deterioration include corrosion from embedded metal, chemical corrosion from extreme soil acidity or alkalinity, thermal wear from expansion and contraction loading, wear from vehicle loading, and design and construction flaws.

Design and Procurement Considerations

Tunnels are assets with extraordinary longevity, and transit agencies must take lifecycle costs into consideration in design. In particular, it is worthwhile to develop a tunnel waterproofing system with maximal durability, to ensure effective drainage, to assess the system's maintainability, and institute careful quality control during construction. Water infiltration is the biggest issue affecting a tunnel's structural integrity. In many cases, leak mitigation is a substantial ongoing cost above and beyond periodic major rehabilitation projects. Careful specification and close inspection of the installed waterproofing system is critical to minimize water infiltration over the structure's design life. Furthermore, the design team should develop a thorough maintenance plan for the waterproofing system, including measures for effective leak mitigation and drainage maintenance.

Since replacement is almost never a viable option for tunnels, construction quality control programs should include relatively high inspection frequency and detail. For example, corrosion is a critical design issue in many tunnel environments. The design process should carefully consider how corrosion will be mitigated, possibly using non-corrosive steel materials (for example, stainless steel for doors and handrails) and corrosion-resistant pumps and pumping systems. Cathodic protection systems should be carefully specified for durability and maintainability. Also, designers may attempt to eliminate or at least minimize stray electrical currents (particularly at locations where excessive leakage may occur and at locations where groundwater may contain chlorides), which can also corrode and weaken critical structures as well as track components. Stray current can also have a detrimental effect on the signal system. In many cases, the corrosion rate must be carefully modeled so that the design robustly accommodates realistic corrosion levels through the design life until a rehabilitation project. Critical construction steps, such as the pouring of concrete over reinforcing steel to minimize delaminations, needs close construction inspection services.

Tunnel design should be carefully coordinated with track design. Since transit rail systems' structural requirements can vary with vehicle and track type, specifications should be carefully reviewed. The design team can mitigate vibration issues in track design to prevent structural cracking. For instance, it is possible to ensure that floating invert slabs for direct fixation can be repaired easily. Numerous agencies have had problems with the isolation pads failing over time, which then caused problems in the track profile.

The tunnel structure must carefully integrate with other design elements like the track and station structures. Transition structures are also important design elements where design defects often occur. For instance, it is important to include expansion joints at locations that are exposed to the atmosphere or at cross sectional locations in the design, such as vent shafts and stations.

The design stage should carefully assess how the tunnel will accommodate tunnel maintenance, including leak mitigation, track replacement, and cleaning. Tunnel space is at a premium since additional space requires a proportional additional investment. However, it is critical to have space available to allow some maintenance work and construction staging to occur without impacting operations. Even transit systems that do not run continuously still must move vehicles and consists among maintenance facilities during non-operating hours. Since tunnels have long design lives, operational needs can change over time—service hours tend to grow longer and service busier—while maintenance needs increase. Tunnel design should account for such needs where possible.

Maintenance and Monitoring Considerations

Specialized maintenance management systems are available for tunnels. Such systems support data collection, planning, and prioritization of maintenance. These systems provide a foundation necessary for the implementation of performance-based tunnel maintenance. The FHWA, together with the FTA, have created the OneDOT Tunnel Management System for tunnel inspections, condition monitoring, and maintenance logging.[39] Commercial products are also available, and although most are focused on roadway tunnels, they offer more sophisticated management and operation functions and features such as integration with the agency's GIS data.

Most heavy rail systems with a high proportion of below-grade right-of-way have an ongoing leak mitigation program conducting maintenance continually and typically managing its work load with a prioritization process. As inspections identify leak issues and work orders are created, the maintenance staff member assigns the leak a priority score. Tunnel leakage is typically prioritized by severity, so the largest leaks—those with highest rate of water inflow—are sealed first. A prioritized approach will minimize damage to the structure and operating systems and effectively manage the leak mitigation program workload. Leaks emanating from structural cracks

[39] http://www.fhwa.dot.gov/bridge/tunnel/

and construction joints can rust reinforcing steel and cause a delamination within 3 to 5 years. Within 5 to 7 years, leaks can cause spalling of the concrete structure.

Capital Rehabilitation and Replacement Considerations

Since tunnel systems typically are not replaced but are rehabilitated, the effectiveness of a transit agency's tunnel rehabilitation program determines its tunnel assets' long-term health and costs. Tunnel rehabilitations may address systems or structures or both.

> As for other assets, tunnel maintenance costs increase over time: tunnel systems and wiring degrades, concrete deterioration accelerates, and the performance of tunnel systems—including ventilation, pumps, and lighting—deteriorates.
>
> Transit agencies can carefully monitor trends using maintenance management systems and move forward with rehabilitations as tunnel elements reach cost, reliability, or safety thresholds.
>
> The most important consideration in a tunnel rehabilitation program is access to the right-of-way. High-use levels can minimize off-line time. Often, a substantial portion of rehabilitation costs is related to construction staging and maintaining service availability. A carefully planned ongoing rehabilitation program can coordinate availability among various programs and help synchronize maintenance rehabilitation efforts.
>
> Continuous rehabilitation must balance workloads and equipment availability and therefore may be a cost-effective measure to address tunnel capital investment needs.

Tunnel owners are increasingly retrofitting tunnels with systems to improve operations and operational safety and address low frequency, high impact risks. Investments in improved ventilation and fire protection to reduce fire risks, features for easier emergency access and egress, improved monitoring technologies, and security. Examples include the installation of more intuitive signage and cues for escape routes and the creation of simplified system control features to reduce incident response and improve response coordination and quality. Many systems have ongoing repair and rehabilitation programs to upgrade existing systems to current National Fire Protection Association (NFPA) and local standards. Transit rail tunnels are often high-capacity, critical-transportation infrastructure, and a tunnel emergency can affect a high number of people directly and cause system outages at critical network location where it is usually more difficult to restore service. Investments in safety and other operational improvements can further mitigate these risks.

Condition Assessment and Performance Monitoring

As mentioned in the (Tunnels) Design and Procurement Considerations section, prior to reception of the tunnel from capital programs for operation, the maintenance team should have in place a comprehensive inspection program for tunnel leaks and overall condition. For agencies with extensive tunnel assets, it may be worthwhile to have an inventory system to track inspections and maintenance by section or location. Close monitoring of both leak issues and maintenance effectiveness are important performance monitoring measures to track structural risk, ensure high quality repairs, and target specific tunnel sections for rehabilitation. Maintenance staff should update protocols and procedures regularly, provide regular and as-needed training, and check work quality carefully.

The FRA requires tunnel inspections every 2 years, and the FTA is in the process of developing inspection guidelines, but transit agencies with extensive tunnel assets can benefit from a more customized approached. Performance-based inspections prioritize tunnel sections based on past inspections and maintenance. While much of tunnel inspection is visual, tunnel maintenance staff can use special inspection and testing equipment to both probe identified issues with more detailed inspection measures, such as sounding and non-destructive or destructive testing, and to spot test randomly to establish baseline conditions. Critical elements, like bolts, gaskets, and the condition of the liner, may require more frequent inspection. It is important to review and update the inspection program and inspection protocols regularly to ensure they reflect the latest practices and requirements. **Table 4-5** provides examples of useful tunnel condition and performance metrics.

Table 4-5. Tunnel Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Tunnels	▪ Condition scores ▪ Cracking repair rate ▪ Water leak repair rate ▪ Maintenance backlog by priority score	▪ Availability ▪ Tunnel length by condition rating ▪ Cleanliness ▪ Drainage/pumping failures

4.2.4 Ancillary Structures

Ancillary structures are a diverse set of assets that would not necessarily share a single lifecycle management approach. Many of the practices and principles outlined for other guideway asset classes apply to ancillary structures. Depending on an agency's mix of ancillary structures, these assets should be addressed through their own lifecycle management plans or as part of other guideway structures lifecycle management plans. Agencies should ensure these assets are tracked in an inventory along with maintenance activities and condition where applicable. Ancillary structures include the following:

- Under-track culverts and crossings
- Systemwide cable troughs and/or duct banks
- Under-track/over-track pedestrian walkway structures
- Retaining walls
- Barriers and noise protection walls
- Information and sign structures
- Fender systems
- Utility hangers

4.3 Industry Standards

The following list outlines any industry standards associated with the lifecycle of the guideway elements asset class:[40]

- **Track**
  - American Railway Engineering and Maintenance of Way Association (AREMA) Manual of Railway Engineering: Serves as a guide of recommended practices for rail planning and covers four main topics:

[40] This supplement defines industry standards as requirements, standards, or guidelines that exist currently or are pending.

track, structures, infrastructure and passengers, and systems management. The track chapter covers design specification, maintenance, and construction.[41]

- AREMA Portfolio of Track Work Plan: consists of plans and specifications of switches, frogs, turnouts and crossovers, crossings, and rails and special track work.[42]
- Federal Railways Administration (FRA) Track Safety Standards, codified under 49 CFR 213: minimum safety requirements for specific track conditions, includes maintenance, inspection, and operations.[43]
- American Public Transportation Association (APTA) Standard for Rail Transit Track Inspection and Maintenance: Represents an industry consensus on practices and standards to help rail transit systems achieve a high level of safety. Topics covered include inspection, condition reporting, corrective action, as well as minimum safety requirements for track components.[44]
- Transit cooperative research Program (TCRP) Report 155 second edition, Track design handbook for Light Rail transit, 2012: provides guidelines and descriptions for the design of various common types of light rail transit track.[45]

- **Bridges**
  - Federal Highway Administration (FHWA) National Bridges Inspections Standards: standards are in place to ensure the safety of the traveling public and support the National Bridge Inventory (NBI). [46]
  - Federal Highway Administration (FHWA) Recommended Framework for a Bridge Inspection QC/QA Program: this framework is used to establish consistency and accuracy of inspections. It includes procedures for quality control and quality assurance, and a list of notable practices from other states. [47]
  - American Public Transportation Association (APTA) Standard for Rail Transit Structure Inspection and Maintenance: Represents an industry consensus on practices and standards to help rail transit systems achieve a high level of safety through incorporation of safety considerations during the inspection and maintenance process. The standard applies to fixed facilities that support or carry loads, such as bridges, tunnels, ancillary structures, retaining walls, barrier (crash walls), communication towers, and culverts. Topics covered include inspection practices and controls, and maintenance.[48]
  - American Association of State Highway and Transportation Officials (AASHTO) Manual for Bridge Evaluation and other guides and manuals: Manual for bridge inspection that ensures compliance with the NBI requirements; other standards cover design, construction, and maintenance.[49]
- **Tunnels**
  - Transit Cooperative Research Program (TCRP) Synthesis 23 – Inspection Policy and Procedures for Rail Transit Tunnels and Underground Structures, Washington, DC, 1997: This report is a compilation of case studies of five transit agencies' rail transit tunnel inspection policy and procedures and a comparison of the different approaches. Part of the purpose of this report is to determine whether or not there needs to be standardized rail tunnel inspection policy and procedures. [50]

---

[41] http://www.arema.org/publications/mre/index.aspx
[42] http://www.arema.org/files/pubs/forms/AREMA_2010_Portfolio_Order_Form-0111.pdf
[43] http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&rgn=div5&view=text&node=49:4.1.1.1.8&idno=49
[44] http://www.aptastandards.com/portals/0/volume5/apta_fs_002_02.pdf
[45] http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_155.pdf
[46] http://www.gpo.gov/fdsys/pkg/FR-2009-12-24/pdf/E9-30469.pdf
[47] http://www.fhwa.dot.gov/bridge/nbis/nbisframework.cfm
[48] http://www.aptastandards.com/portals/0/volume5/apta_fs_001_02.pdf
[49] https://bookstore.transportation.org/category_item.aspx?id=BR
[50] http://onlinepubs.trb.org/onlinepubs/tcrp/tsyn23.pdf

- Federal Highway Administration (FHWA) and Federal Transit Administration (FTA) Highway and Rail Tunnel Inspection Manual FHWA-1F-05-002, 2005: Provides uniformity and consistency in assessing the physical condition of various tunnel components. The manual defines tunnel construction and systems, and discusses inspection procedures and documentation.[51]
- Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual, 2005: Guidelines and practices for preventive maintenance of tunnel structures and mechanical/electrical/track systems within and rehabilitation methods.[52]
- Transit Cooperative Research Program (TCRP) Report 86, Volume 12, National Cooperative Highway Research Program (NCHRP) Report 525, Volume 12, Making Transportation Tunnels Safe and Secure: The objective of this report is to develop safety and security guidelines for transportation tunnel owners and operators. The report uses case studies to study past tunnel disasters, identifies tunnel vulnerabilities and countermeasures, and discusses system integration.[53]
- National Fire Protection Agency (NFPA) 130 Standard for Fixed Guideway Transit and Passenger Rail Systems 2000 Edition: Standard for fire safety protection of underground, surface, and elevated fixed-guideway transit and passenger rail systems. This includes stations, tunnels, emergency ventilations systems, vehicles, emergency procedures, communications, control systems, and vehicle storage areas.[54]
- Federal Highway Administration (FHWA) Technical Manual for Design and Construction of Road Tunnels - Civil Elements, 2011, Chapter 16: technical manual with guidelines for planning, design, construction, and rehabilitation of road runnels.[55]

- **Ancillary Structures**
  - American Public Transportation Association (APTA) Standard for Rail Transit Structure Inspection and Maintenance: Represents an industry consensus on practices and standards to help rail transit systems achieve a high level of safety through incorporation of safety considerations during the inspection and maintenance process. The standard applies to fixed facilities that support or carry loads, such as bridges, tunnels, ancillary structures, retaining walls, barrier (crash walls), communication towers, and culverts. Topics covered include inspection practices and controls, and maintenance.[56]
- **Pavement and Roadway**
  - Manual for Uniform Traffic Control Devices: National standard for traffic control devices (e.g. signage, signals, markings) on any street, highway, bikeway, or private road open to public travel. [57]
  - American Society for Testing and Materials (ASTM) Road and Paving Standards: Standards for the specifications and test methods for the material, physical, mechanical, performance, and application requirements of road surfaces and pavements.[58]
  - List of state roadway design manuals.[59]

[51] http://www.fhwa.dot.gov/bridge/tunnel/inspectman.pdf
[52] http://www.fhwa.dot.gov/bridge/tunnel/maintman00.cfm
[53] http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_525v12.pdf
[54] http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=130&cookie%5Ftest=1
[55] http://www.fhwa.dot.gov/bridge/tunnel/pubs/nhi09010/index.cfm
[56] http://www.aptastandards.com/portals/0/volume5/apta_fs_001_02.pdf
[57] http://mutcd.fhwa.dot.gov/pdfs/2009r1r2/pdf_index.htm
[58] http://www.astm.org/Standards/road-and-paving-standards.html
[59] http://www.fhwa.dot.gov/programadmin/statemanuals.cfm

- American Society for Testing and Materials (ASTM) Standard Guide for Pavement Management Implementation: Guide for process and steps when implementing and operating pavement management systems. [60]
- American Society for Testing and Materials (ASTM) Standard Guide for Network Level Pavement Management: Guide for network level Pavement Management Systems to ensure the system selected aligns with agency needs and requirements.[61]

The Metropolitan Transportation Authority New York City Transit (MTA NYCT) is the nation s largest subway system and its second oldest. Since the subway system operates day and night, the intensity of its operations makes maintenance extremely difficult, so the agency continually seeks improvements in its construction methods and materials to increase the longevity of its track system. MTA NYCT was quick to embrace the technological advances in rail friction management. Curve lubrication is a staple of MTA NYCT s operating plan, as sharp curves and high traffic can accelerate rail wear dramatically. MTA NYCT lubricates the gauge side of its running rails as well as restraining rails. In addition, MTA NYCT has installed dispensing units for top of rail friction modifiers at sharp curves adjacent to stations where they have greatly diminished wheel squeal.

In addition, MTA NYCT is working toward reducing the modulus of its tunnel and open deck aerial track to levels normally seen in ballasted track. By methods such as installing elastomeric pads on timber tie open deck track or installing resilient tie blocks in new subway track, MTA NYCT is targeting track modulus values in the range of 4,000 pounds per square inch, which are 25 to 50 percent below the modulus values typical for those track forms. MTA NYCT is looking to attain key benefits such as lower impact loads, lower noise levels, and increased track component life.

[60] http://www.astm.org/Standards/E1889.htm
[61] http://www.astm.org/Standards/E1166.htm

Chapter 5

Systems

5.1 Asset Class Overview

The systems asset class category includes a diverse set of monitoring and control systems that support core operational functions. All of these systems are critical to the transit system, providing power, communications, revenue collection, security, and safety controls. This asset class includes the following:

- **Security** provides protection for customers and employees from threats and vulnerabilities, both internal and external to the system. It comprises both monitoring and control systems.
- **Traction Power Electrification** provides supply and distribution of propulsion power for electric-powered trains and trolley buses and includes alternating current (AC) and direct current (DC) systems. Subsystems include overhead contact and third-rail systems, distribution, and substations.
- **Signals/Automatic Train Control (ATC)** refers to the wayside and onboard equipment responsible for safe train operation and traffic control.

- **Communications/Monitoring/SCADA**[62] refers to various telecommunication, monitoring, announcement, protection, and control equipment necessary to manage and maintain operation of the entire transit system.
- **Revenue Collection** refers to the equipment, both mechanical and automated, and supporting systems used to collect transit revenues, and in some cases, to collect data, including ridership and service performance data.

Many systems assets have built-in redundancies and are self-monitoring because of their critical nature and so are able to meet high reliability standards. Some systems assets, such as elements of many automatic fare collection and security systems, need only minimal maintenance and are simply replaced as they (or their components) fail. Nevertheless, transit agencies can still realize important performance benefits by improving asset management practices. Lifecycle management planning, including total lifecycle costing, can support a more objective decision-making framework in the planning and procurement phases that supports design and procurement of more cost-effective systems. Lifecycle management planning also ensures processes are in place that track systems' performance and support ongoing performance improvement including better reliability and lower maintenance costs.

Most systems are owned and maintained in-house; however, there are exceptions. As more transit agencies enter into Design-Build-Operate-Maintain (DBOM) contracts for new rail lines, many, if not all, of the associated systems (in particular, traction power electrification and automatic train control) are maintained by a third party. Transit agencies frequently use contractors to supply, operate, and maintain fare collection, communication systems, and even some security systems. Also, technology systems tend to have shorter design lives and technology lifecycles than most other assets, meaning that vendor support and obsolescence are important issues for the replacement schedule. Instead of rehabilitations, systems often require specific upgrades or customization—for instance to device firmware—that may still be covered as a capital expense. All of the asset classes (and associated lifecycles) included in the systems category are organized in a proposed asset hierarchy in **Table 5-1**.

[62] SCADA refers to supervisory control and data acquisition systems which support remote monitoring and control of equipment and devices. SCADA is integrated with an agency's enterprise communications infrastructure.

Table 5-1. Systems Asset Class Proposed Asset Hierarchy

<table>
<tr><th>Asset Class</th><th>Sub Assets</th><th colspan="2">Related Assets</th></tr>
<tr><td>Security</td><td>▪ Closed circuit surveillance
▪ Access control
▪ Intrusion detection
▪ Emergency operations center</td><td colspan="2">▪ Surveillance cameras
▪ Camera control equipment/workstations
▪ Access control management system
▪ RFID readers / electronic door locks
▪ Emergency operations center communications equipment</td></tr>
<tr><td>Traction Power Electrification Systems</td><td>▪ Substation
▪ Distribution
▪ Overhead Catenary System (OCS)
▪ Third Rail</td><td>▪ Pre-engineered switchgear and/or control equipment enclosures and protective relaying system
▪ Grounding systems
▪ Transformers (i.e., traction and facility power)
▪ Transformer - rectifier units
▪ Supporting steel structures (for equipment and/or conductors)
▪ Trackside disconnect switches
▪ Overhead contact system (i.e., support structures, tension wires, OCS assemblies, messenger and contact wires)</td><td>▪ Negative feeder distribution system (for 2 x 25 kV autotransformer system)
▪ Contact rail system
▪ Leakage current mitigation
▪ Underground ductbank and structures
▪ Feeder cable distribution system
▪ Impedance bonds
▪ Emergency trip dystems/yransfer yrip dystem
▪ Return cable system
▪ Uninterrupted power supply (UPS)</td></tr>
<tr><td>Signals / Automatic Train Control (ATC)</td><td>▪ ATC equipment
▪ Wayside equipment
▪ Cable and cable transmission system
▪ Equipment enclosures
▪ Car-based equipment
▪ Centralized control hardware, software, and workstations
▪ Railroad-Highway grade crossing equipment</td><td>▪ Train detection equipment (track circuits, axle counters)
▪ Signals
▪ Switch machines
▪ Equipment enclosures (cases, pre-engineered bungalows, ATC rooms)
▪ ATC local cable and cable supporting structures (ductbank, raceways)
▪ Wayside ATC logic equipment
▪ Car-based ATC logic equipment (including cab display units)
▪ Train to wayside, wayside to train communication equipment (loops, antennas, transponders, train stops, tags)
▪ Control center software and hardware for centralized ATC control, scheduling software (if interfacing with ATC)
▪ Dedicated vital communication links and associated communication equipment.</td><td>▪ ATC power supply
▪ Underground/above-ground ductbank and wire-way system
▪ Grounding equipment
▪ Battery chargers and batteries (or UPS)
▪ Platform doors control system (where applicable)
▪ Specialized diagnostic equipment
▪ Specialized simulation equipment
▪ Event recorder or data warehouse system
▪ Local control panels
▪ Impedance Bonds
▪ Junction boxes
▪ Cables and wire
▪ Grade crossing gates and flashers
▪ Grade crossing detector loops</td></tr>
</table>

Table 5-1. Systems Asset Class Proposed Asset Hierarchy (continued)

Asset Class	Sub Assets	Related Assets
Communications/ Monitoring/ SCADA	▪ SCADA system ▪ Emergency management panel/system ▪ Fire alarm system ▪ Wide area networks (WAN)/metro area network ▪ Cable/data transmission system ▪ UPS systems ▪ Telephone ▪ Radio ▪ Public address and VMS (variable message sign) ▪ Facility management and control systems ▪ Core IT Systems	▪ Fiber-optic cable system ▪ Public address/variable message sign/transit passenger information system equipment ▪ Radio equipment at the base station and antenna ▪ Wayside communications equipment cases ▪ Underground ductbank and structures ▪ Control and low-voltage power cable system ▪ Radiating and non-radiating cable distribution system ▪ Hazard detection systems (inert/combustible gases, biological, radiological) ▪ Climatic & environmental monitoring (water level, high ambient temperature, seismic, high wind) ▪ Servers, computers, work stations, and supporting equipment and racks
Fare Collection	▪ Farebox ▪ Point-of-sale devices ▪ Money room ▪ Electronic settlement system	▪ Bill conveyor ▪ Bill and coin authenticators ▪ Farebox vault ▪ Onboard card interface devices ▪ Central processing unit ▪ Ticket vending machines ▪ Retail ▪ Cashless ▪ Administrative ▪ Coin sorters and counters ▪ Dollar bills sorters and counters ▪ Probe units ▪ Transportable vault

5.2 Lifecycle Management Practices

Most systems assets have a single asset owner who oversees the asset lifecycle from procurement to disposal. However, most systems assets are installed on or integrated with other assets and so asset management measures may rely on the cooperation of multiple departments. Transit system assets have several issues specific to the class:

- For most systems, successive technology generations are not necessarily interoperable and must be operated in parallel if there is any overlap in asset deployment.
- Proprietary technology can limit the flexibility of transit agencies in selecting vendors for spare parts, modifications, and operation of systems assets.
- For many systems, rapid product evolution can lead to equally rapid system obsolescence and to scarcities of spare parts and lack of support for legacy systems.
- Systems tend not to have the same range of rehabilitation options available to other asset classes. In many cases, there is limited maintenance until replacement, or in the case where a rehabilitation procedure exists, it is well defined. For this reason, most asset management practices for systems assets focus more on realizing benefits in design and procurement rather than on improving maintenance and rehabilitation practices.

For these reasons, the asset management approach for transit systems can be more limited than for other categories. Nevertheless, the approach remains similar in many respects. An asset owner should identify the investment requirements associated with the asset's lifecycle (including design requirements, preventive maintenance activities, and rehabilitation) and the associated costs. This information, along with the risk of not making these investments, should be incorporated into the lifecycle management plan for each system. The following describes the lifecycle activities and considerations that are specific to each of the systems asset classes.

5.2.1 Security

Security systems are deployed both on board revenue vehicles and at fixed facilities, including at stations and facilities and on the right-of-way. The primary two security systems are closed circuit video cameras (CCTV) and access control systems. Related to access control systems, transit agencies are increasingly using intrusion detection systems. The following outlines lifecycle management considerations for the design, preventive maintenance, replacement, and performance and condition assessment of security systems.

Design and Procurement Considerations

Reliability is a primary determinant of ongoing security asset costs. Security systems typically interface with public spaces and face many of the general design requirements of passenger facilities. The equipment must be able to sustain the temperature fluctuations, weather conditions, cleaning activities, and passenger use typical of the facility. CCTV cameras are typically placed out-of-reach and may be difficult to inspect and replace. While many inexpensive camera options exist, reliability can vary significantly, and replacement labor costs often outweigh the initial savings of a cheaper, less reliable camera option. In such cases where installation and labor costs outweigh technology costs, agencies should emphasize reliability in the selection of products.

A careful implementation strategy together with a systems engineering approach can minimize technology changeover costs. Interoperability is a significant issue with security systems. While new generation security systems often use digital technologies that have significantly cheaper components and provide higher performance and more features, high installation costs can be a significant barrier to a rapid changeover, leading to significant periods with parallel systems, higher administrative costs, and separate policies for data storage that may lead to lost evidence or other issues. Access control systems are usually installed on a facility-by-facility basis, but managing permissions on parallel systems is more likely to lead to issues such as errors in permissions and will raise administrative costs. Complex technology roll-outs for security and other systems need an implementation plan based on comprehensive systems engineering that recognizes such obstacles and identifies strategies to minimize the risk of system outages and cost overruns from unforeseen issues.

The use of proprietary technology is a significant issue for systems assets, including security assets. Systems that use standard platforms usually allow a transit agency to select operating contractors competitively and may benefit from lower component and upgrade costs. Procurements should give preference to security systems that can be maintained by multiple local vendors to allow for a maintenance contract to be rebid every few years to maintain competitive pricing.

Maintenance and Monitoring Considerations

Transit agencies need a clear understanding of the lifecycle costs and effectiveness of their security investments. The transit industry's greater focus on security issues has often lead to higher investment in security assets. While capital outlays are often grant-funded with modest costs, the financial implications for operations can be serious. More cameras require more staff members for monitoring, additional data storage infrastructure, and ongoing commitment to higher security levels. Transit agencies must carefully consider the sustainability of such security investments and carefully prioritize funds to address safety and risks in ways that minimize or even lower costs. Vandalism and crime on transit vehicles and in stations can have significant negative consequences, but security systems investments can have diminishing returns and cannot substitute for a comprehensive approach to such issues. Ongoing data collection from security operations can support benchmarking of the security system's value and help feed objective information to inform new investments.

Agencies may be able to take advantage of opportunities to contract with vendors for security system operations and management. Low component costs and high labor costs can make preventive maintenance activities an inefficient use of resources for transit agencies. Depending on the system, a contract can cover all system maintenance, which is typically minimal for security systems. Components receive little if any maintenance and are simply replaced after failure. Any maintenance conducted is typically unplanned or reactive. If maintenance is a concern, the security vendor should be required to conduct preventive maintenance in accordance with the manufacturer's recommendations. Transit agencies may also find cost management benefits to leasing technology systems like security systems that require minimal (relative to other assets) installation, maintenance, and on-site support from the vendor.

Capital Rehabilitation and Replacement Considerations

Transit agencies must balance the trade-off between the lower costs or increased utility of new products and the lifecycle cost implications of early retirement of a system. For most systems' assets, performance modeling is most critical at the procurement and replacement stages to understand the implications of upgrading to a new system, including changes in infrastructure, business, and other requirements.

> Condition assessments may make sense for third-rail and OCSs, faregates, and ticket vending machines to support a performance-based maintenance and rehabilitation program, but for many technology systems, transit agencies must rely on simpler replacement heuristics—such as whether an asset is no longer under warranty or whether it meets sufficient functional criteria—to cost-effectively plan replacements.
>
> The procurement and replacement stages of the asset lifecycle are opportunities to evaluate performance and business requirements, improve system design, and set reliability goals.

Performance monitoring consists mainly of tracking those assets with lower reliability and availability statistics and targeting them for improvement with better components or with a system upgrade.

Systems investments' benefits, especially in security, can be difficult to quantify, but transit agencies should seek to assign and model costs and benefits, where possible, to add transparency to decisions. Security equipment typically has a lifespan much longer than product lifecycles. Agencies have maintained CCTV systems for 25 years or more before upgrading to internet protocol (IP)-based digital camera systems. As transit agencies upgrade their technology, they must also account for the digital communications infrastructure they have in place. Active digital video cameras require significant network bandwidth and up-to-date supervisory control and data acquisition (SCADA) systems in passenger facilities.

Condition Assessment and Performance Monitoring

For assets like security systems, the most common measure of performance availability (whether the asset is in service). A standard availability measure—percentage of cameras in service, for instance—captures the existing maintenance need or backlog. A basic inventory allows the easy tracking of availability and also supports reliability analysis through failure rate modeling. For assets like cameras, with high numbers deployed with relatively short useful lives, such reliability modeling can easily identify performance issues associated with particular models, locations, or other factors. The more detailed the inventory, the more effective the performance modeling. For security and other assets, agency staff must evaluate the trade-off between a more detailed inventory and the marginal cost of collecting and tracking the additional data. High-quality business processes help to reduce data collection effort and costs and maintain data quality. **Table 5-2** provides examples of various condition and performance measures for security systems.

Table 5-2. Security Systems Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Security	▪ Fail-safe design ▪ Average age ▪ Obsolescence rate	▪ Onboard system availability/uptime ▪ System coverage ▪ System failures (intrusions undetected, false alarms, etc.) ▪ Reliability (measured in down time rate or mean time between failure) ▪ Design redundancy ▪ Comparison of observed incident response time vs. unobserved incident

Transit agencies can track security incidents as a measure of security systems' effectiveness. Careful tracking of incidents by location, type, and other characteristics can help with analysis of security systems' performance and value. If possible, transit agencies should prioritize identified security needs and address them accordingly, balancing prioritization with costs.

5.2.2 Traction Power Electrification

Traction power electrification systems distribute power for electric trolley bus, streetcar, and light rail and heavy rail systems, and will likely be increasingly used for commuter rail in the future. Traction power electrification systems typically fall into two major categories: those with an overhead catenary system (OCS) and those with a third-rail system. The latter type is typically found in heavy rail systems using exclusive guideway because third-rail systems usually have lower maintenance and replacement costs but represent safety issues in an unsecured right-of-way. Systems with shared or unsecured rights-of-way use OCS to increase safety and allow mixed-traffic and grade-level crossings, and include a large number of infrastructure assets, including poles and tension wires. Overhead catenary systems typically use underground ductbanks often shared with other public works electrification and utilities, while heavy rail systems may have dedicated ductwork for electrical systems that is usually easier to access. Otherwise, the two systems share similar elements and face similar asset management issues and challenges. Transit agencies in the U.S. are also increasingly considering diesel or diesel-electric multiple units (DMU) as a way to reduce cost by avoiding the need for traction power electrification systems. These two electric-based traction-power options are most appropriate for light rail but have been considered for commuter rail systems. This section describes lifecycle management considerations for the design, preventive maintenance, replacement, and performance monitoring of traction-power electrification systems.

Design and Procurement Considerations

As for other major procurements, early involvement of vendors in design can both reduce the vendors' cost of bidding and help the agencies arrive at a better-priced solution. While traction-power electrification systems are composed of well-established components, there remain significant design issues which determine the system's cost to construct and cost to maintain. Important design considerations include the placement of infrastructure to support the overhead catenary system and the use of reliable system components to ensure overall system reliability. Vendor involvement can help select an optimal design approach to minimize costs while meeting performance specifications.

Transit agencies should consider alternate methods of contracting—such as performance-based contracting—where the vendor provides not only the equipment but also an availability guarantee. Increasingly, contractors and vendors are open to operations and maintenance roles. The vendor is the exclusive maintainer of the equipment and everything except asset ownership is transferred to the vendor. Because OCS has a useful life in the neighborhood of 30 years, the transit agency may need performance metrics to ensure the system's condition is maintained to appropriate levels and ensure contractors do not defer maintenance.

For the recent traction power electrification procurements for Exposition Line Phase Two and Foothill Extension Line Phase One, the two construction authorities selected a single substation design for the two similar rail lines. The authorities are procuring substation equipment through one performance based contract for the two lines. This joint procurement will allow LA Metro to find efficiency in their procurement process, save on spare parts, and minimize the training requirements of maintenance staff.

A tight quality assurance and quality control (QA/QC) regime is a necessity for procurement. Traction-power electrification systems use high voltage connections and complex electrical systems, so safety is a critical issue. Close inspection of design and construction work can identify potential safety issues and can also improve the system's reliability. For both the design and construction phases, the transit agency should ensure that a robust QA/QC program is in place, including comprehensive inspections and testing.

Maintenance and Monitoring Considerations

Traction power electrification systems are relatively complex systems that can benefit from having a lifecycle management plan in place to map out the inspection, maintenance, rehabilitation, and replacement needs of system elements and components with a focus on substations and third rail or OCS. The traction power system is composed of sections that provide a means for isolating individual sections of the third rail or OCS for maintenance purposes or attendance to track incidents.

Generally, scheduled or preventive maintenance activities focus on the third-rail and OCS—as opposed to the upstream distribution system—which experience wear from vehicle use and the surrounding environment. Regular inspections support condition-based maintenance and replacement of these elements.

Maintenance staff can monitor substation performance and then conduct periodic inspections and perform maintenance as needed.

Vehicle-based monitoring systems can also help identify specific acute issues.

Previous maintenance and inspection activities can be used to predict maintenance needs and schedule future activities.

Providing maintenance staff with mobile communications technology and handheld computers to support field-based maintenance increases technicians' autonomy and can raise maintenance performance—including efficiency and quality—and improve data collection. Traction power electrification equipment is distributed throughout the guideway, but not all system maintenance can be completed in the field at the time issues are identified. Regular maintenance consists mostly of visually inspecting substation equipment, including checking water, batteries, and fire extinguishers. Handheld computers reduce the time needed to enter inspection data. By providing access to documentation and the maintenance management system, mobile and handheld computing technology can also enable technicians to complete a wider range of tasks while more accurately recording work activities. The maintenance data can be used to improve work procedures and increase the effectiveness and efficiency of field staff. For instance, historical maintenance data for the traction power electrification system can help identify common failure modes and locations, and maintenance staff can then ensure they have sufficient training to address these issues and proper equipment in the field, along with optimized inspection routines.

Capital Rehabilitation and Replacement Considerations

Since traction-power electrification systems are integral elements of the guideway, transit agencies may realize significant cost savings from comprehensive capital rehabilitation programs that coordinate rehabilitation and replacement with other asset elements, especially track. For electric-powered transit vehicles running in the public right-of-way, rehabilitation projects may require coordination with the public works department for pavement maintenance and rehabilitation and sewer or ductbank replacement. To make such joint projects effective, it is helpful to have integrated condition monitoring and capital planning processes. As for other guideway assets, work on traction-power electrification systems necessitates careful planning of system availability.

Condition Assessment and Performance Monitoring

Asset owners are increasingly using active monitoring capabilities to monitor systems' performance. As products increasingly include monitoring features, and sensors become less expensive and easier to install, agencies are using active monitoring to collect data more cost effectively and identify issues in real time, thereby improving response times and improve decision making. Although many elements of a traction-power electrification system are usually self monitoring and include built-in redundancy to reduce the risk of failure, transit agencies must ensure they have in place the configuration and procedures to effectively use such features. Systems diagnostics can significantly improve system reliability and performance, as shown in the following examples:

- Tracking of power use at the component level can identify components with issues. Being able to monitor a component to get early warning of imminent failure allows maintenance resources to be directed more economically and failures to be avoided. Transformers and cables can now be automatically tested to determine the degradation of components.

- Transit agencies are increasingly using energy management systems to conserve power and save costs.
- In systems using direct-current traction power, test stations can be installed in bridge and tunnel structures to measure the amount of stray current flowing through the structure outside the return rails. This enables the owner to implement remedial measures if stray current reaches unacceptable levels and avoid costly damage to structures or adjacent facilities.

To take advantage of these opportunities, transit agencies need an up-to-date SCADA and communications system in place and the back-end data system to store information.

Vehicle-based monitoring technologies can also provide low-cost data collection to improve system performance. Including cameras and global positioning systems (GPS) on vehicles in the design specifications puts in place a system to collect asset performance data from the operations perspective. The cameras capture when the pantograph loses contact with the OCS and records the location and issue. Maintenance staff can also run special trains to measure the differential movements of the overhead wires to identify points where they are not within defined tolerances, which are then addressed through scheduled maintenance to minimize failure risk. Optical technologies are being applied overseas to OCS infrastructure to assess the following:

- Changes in OCS infrastructure devices
- Detection of broken or deformed or missing parts
- Detection of corrosion
- Inspection of OCS infrastructure
- OCS geometry
- Contact wire wear
- Pantograph/wire interaction (for example, contact forces pantograph pan vertical accelerations)
- Detection of electric arcs (for example, location, duration, intensity, and quantity)
- Contact wire thermogram.

Engineers can use recorded data to analyze past failures and identify predictive signatures that allow targeting of preventive maintenance. Reliability data allow retroactive assessment of maintenance program performance. **Table 5-3** lists additional examples of common performance measures for traction-power electrification systems.

Table 5-3. Traction Power Electrification Systems Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Traction Power Electrification	▪ Spare parts availability ▪ Fail-safe design	▪ Availability ▪ Mean time between failures ▪ Number of failure occurrences, including failures with no impact to train service

5.2.3 Signals and Automatic Train Control

For fixed-guideway systems, transit agencies are responsible for all traffic control unless they operate under an agreement with a separate track owner, such as a freight railway. Signal and train control systems support safe train operation by precisely monitoring and directing traffic. These systems are usually fully integrated with an agency's communications and SCADA systems. The following outlines lifecycle management considerations for the design, preventive maintenance, and replacement of signals.

Design and Procurement Considerations

Since train control systems extend over the entire guideway network and are composed of discrete classes of equipment, transit agencies can benefit from designing the train control system to use standardized system architecture and modular equipment. Maintaining standard architecture allows for easier understanding of the system supporting higher quality maintenance and improved safety. Extensive systems are prone to becoming heterogeneous over time, which can reduce the efficiency of field maintenance, increase the necessary parts inventory, and lead to issues with maintenance staff's system understanding and with maintenance quality control. Standardized system architecture helps ensure maintenance staff adhere to standard maintenance procedures and maintain the the system's reliability, maintainability, and integrity.

Communications based train control is a more recent approach that can eliminate some of the communications infrastructure needed for train control in the guideway. It replaces track circuits with radio communication. By eliminating insulated joints, power and signal bonding, as well as local track cable, there may be significant savings in lifecycle costs in addition to operational benefits from shorter headways. However, such train control systems typically rely on costly proprietary systems to run, and partial upgrades are usually not a wise choice from implementation and operations perspectives.

In addition to mapping preventive maintenance, reactive maintenance, and rehabilitation needs, the train control lifecycle management plan should also plan and prioritize technology upgrades to avoid moving away from a standardized architecture and approach. Like other systems assets, train control systems are subject to a product lifecycle, and new technology and approaches can often make system components obsolete within their design life. A systems' engineering approach and plan ensures the automatic train control (ATC) system's reliability through a changeover process and accounts for the particular features and needs of each system, maximizing reuse of existing components to minimize overall cost.

When selecting a signal system for a new rail line, operational needs and compatibility with the existing signaling system should be a guiding element in the decision making. For example, if there is a potential that the line will run at-grade, it would make no sense to invest in a fully driverless ATC system, as its full capabilities would never be realized. Furthermore, uniformity in operational procedures (such as signal indications) and onboard ATC equipment among various rail lines will have lower annualized lifecycle costs and lessen risks because it will ease equipment and employee transfers between lines and prevent accidents due to confusion over operating procedures on a specific line.

In general, it is important to maintain a technology and investment roadmap for the ATC system. A roadmap may include the strategy for successive system upgrades consisting of gradual or total replacement, prioritization of system elements for retirement and replacement, prioritization of new features and capabilities to add, and the systems engineering approach to support deployment, integration, testing, and overall project success.

As part of acceptance, vendors and contractors can provide an asset inventory to the transit agency's specification. Transit agencies do not always manage to update inventories at project delivery. For train control systems and other systems assets, transit agencies can address this issue by including configuration management requirements in the contract, so that data associated with all assets are included when the asset is turned over to the owner. These may include identification numbers, quantities, locations, and parts requirements. It is also possible to specify setup requirements for business information systems, including what data are needed, the data format, and business process specifications.

Maintenance and Monitoring Considerations

A straightforward reliability-based approach to equipment performance can help transit agencies focus their maintenance resources and performance improvement efforts. Reliability is easily tracked using typical digital maintenance records. Reliability analysis identifies weak points in the system, which can be addressed through component or system architecture upgrades. Train control systems are typically robust in terms of reliability, fail safes, and instrumentation. Software usually includes comprehensive diagnostics that can be complemented by in-person inspections and tests. Simplified system architecture and modular design makes maintenance increasingly easy. With communications increasingly radio-based or on a shared SCADA platform, maintenance consists mainly of identifying issues and replacing or tuning components.

In addition to condition-based or reliability-based maintenance, a planned maintenance regime may be required under FRA regulations. This planned maintenance regime can take into account the physical proximity of various assets to allow for multiple equipment to be inspected during the same visit, thus during travel times and increasing efficiency and savings. A carefully defined asset inventory linked to the maintenance regime can help ensure compliance with such regulatory requirements by tying particular requirements to the individual assets impacts and programming and tracking mandatory inspections and maintenance. For field work, mobile devices allow easy processing of work orders and access to documentation. Digital representations of system architecture along with detailed maintenance procedures and diagrams can improve the effectiveness of field diagnostics and maintenance. Both innovations support improved quality control of maintenance work.

Capital Rehabilitation and Replacement Considerations

Lifecycle management of train control systems typically emphasizes replacement over rehabilitation because of the nature of the assets. Components may be replaced based on failure, quality issues, energy efficiency, or obsolescence. If the asset inventory is carefully maintained, transit agencies can more easily plan such replacements to ensure upgrades are comprehensive and optimally timed. As systems age, they can develop a mix of old and new signaling systems. Replacement efforts should prioritize and aim for interoperability, compatibility, uniformity, and ease of migration along with periodic comprehensive updates. Over the last 50 years, intended useful lives for train control systems have shortened as innovation has accelerated and proprietary systems become more common. Modern interlocking systems have much shorter lifecycles (15- to 30-year lifecycles as opposed to 100-year lifecycles) because of electronics or software becoming obsolete or outdated. As result, transit agencies should plan technology transitions more carefully.

Condition Assessment and Performance Monitoring

Train control systems can have a high cost of failure, so management of these assets focuses heavily on risk. Even basic systems assets can benefit from tracking performance measures like failure rates and reliability scores based on elementary data from the asset inventory. For many technology systems, performance monitoring takes a binary approach: systems are either functional or out of service. Therefore, it is natural to take a reliability-based approach to systems assets management. Under such an approach, asset managers identify higher risk assets—those that are more prone to failure and cost more to fix—and target them for preventive maintenance and upgrades to address specific failure modes or for replacement with more reliable systems. To the extent condition assessments are available for train control system components, they may serve as the basis for reliability modeling. Measures of system use, such as hours in service and vehicle miles, can also provide inputs for reliability modeling.

Inspection and testing programs ensure safe system operation and a precautionary approach to maintenance. As result, ATC maintenance activities should combine scheduled maintenance with reactive maintenance based on condition inspections and tests. Any system containing moving parts (such as switch machines and circuit controllers, highway crossing apparatus, mechanical train stops, and searchlight signals) is required to be inspected at specific intervals in order to prevent unsafe conditions and to maintain its manufacturer's warranty (if applicable). Many properties have also instituted inspection and testing programs for ATC logic (for example, relays and sensors). Although these devices are designed to fail safely, their physical inspection offers the opportunity to detect and correct conditions that would otherwise result in disruption of service. It is especially important to test system functions that are used only in special operating modes. For instance, uninterrupted power supply (UPS) components may experience only minimal use, often when safety is an important concern. **Table 5-4** provides condition and performance metrics for ongoing monitoring of lifecycle management practices.

Table 5-4. Signal and ATC Systems Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Signals/Automatic Train Control	▪ Spare parts availability ▪ Fail-safe design ▪ Percent of assets over design life	▪ Mean time to failure ▪ System downtime ▪ Number of control incidents ▪ Inspections completed on time

Performance monitoring and improvement programs for asset management address risk, ensure assets can meet level of service requirements, and provide information from which assets can be managed across their lifecycles. For systems assets, basic data tracking includes (1) having an asset inventory in place with key attributes for each asset (system model, installation date, location, etc.), and (2) having a work-order system in place to track maintenance and replacement in the inventory by asset type. Inspections, system diagnostics, SCADA-based system management and monitoring, and other data collection can also support performance measurement and improvement. Condition assessment and performance monitoring should result in the following activities:

- Address immediate issues by completing reactive maintenance activities.
- Proactively identify any preventive maintenance and rehabilitation needs.
- Assess the quality and effectiveness of maintenance and rehabilitation activities.
- Collect condition and performance data for investment scenario evaluation and performance modeling and improvement.

Given the critical safety concerns related to train control, transit operators must regularly assess and update their inspection approach. The AREMA 2012 Communications and Signals Manual of Recommended Practices[63] has ATC system testing recommendations, which describe testing procedures and outlines specific conditions to be verified during each test. Although the AREMA manual contains equipment testing recommendations, it does not establish any time interval at which these tests must be performed. Transit properties that fall under FRA jurisdiction are required to follow requirements of U.S. Code Part 236, which mandates specific test intervals (for example, vital vane and direct-current relays should be tested at least once in 2 years). Properties outside of FRA jurisdiction should establish inspection frequency and required test results based on AREMA and manufacturer's recommendations.

5.2.4 Communications/Monitoring/SCADA

Transit communications systems can span a range of functions and assets. Bus systems typically have few fixed field assets requiring SCADA systems to support remote control and monitoring of systems. Most communication requirements relate to vehicles and are radio-based and supported by computer-aided dispatch. In some cases, a bus agency will have a fiber-optic or other data connection among its bases and administrative facilities. For rail

[63] http://www.arema.org/publications/cs/index.aspx

systems, hard-line communication lines connect control centers with assets along the guideway, including train control systems, traction-power substations, and security systems. Agency operations, maintenance, and security staff also rely on radio communications for both voice and digital functions. Hard-line communications typically lie in the guideway ductbanks, while radio communication systems may use both transit and non-transit properties to provide appropriate coverage to the service area. SCADA systems provide the interface between hardware systems and the core communications network and are distributed throughout the transit system. The following outlines lifecycle management considerations for the design, preventive maintenance, replacement, and disposal of Communications/ Monitoring/ SCADA systems.

Design and Procurement Considerations

Alternatives methods of contracting, such as performance-based contracting, where the vendor provides not only the equipment but also an availability guarantee, are increasingly common and supported by vendors. Transit agencies may also be able to use vendors to provide radio communications on an availability basis. Vendors can help transit agencies meet technological and security challenges. The vendor is the exclusive maintainer of the equipment and everything except asset ownership is transferred to the vendor. While transit agencies may require their communications systems to meet specific technical specifications or standards, procurements that emphasize functionality without overly prescribing standards and approach can help improve the cost-effectiveness of the procurement and the number of responsive bids.

Sharing communications infrastructure with other local agencies, such as law enforcement and emergency response, can save costs but may also introduce issues related to common platforms and integration and to system transparency and troubleshooting. Interagency agreements should carefully assign asset management responsibility and procedures to provide a clear framework for coordination and to minimize the response time to technical issues. Transit agencies should ensure a shared system can accommodate its long-term technical needs and expected system growth. As another strategy to save costs, transit agencies undertake joint hardware procurements with other local government agencies or transit agencies with similar needs. Some agencies are using Indefinite Delivery and Indefinite Quantity (IDIQ) contracts to lock in supply and prices. This can help to avoid parts obsolescence.

Agencies should ensure that SCADA assets are closely tracked through of the asset inventory, and older and relatively more important systems receive priority for replacement. Larger transit systems may have extensive SCADA assets in place. To the extent possible, all of the agency's departments and technology systems should share the same SCADA platform. Using standardized building blocks and modular equipment design and implementation allows off-site assembly and testing, reduces on-site testing time, makes compatibility and interoperability seamless, and reduces the types of assets to be maintained. An inventory can help support system planning to target key elements for replacement based on obsolescence, lower reliability, and requirements of new systems supported by the SCADA. Lifecycle management planning should address SCADA renewal and map an approach targeting units for replacement based on functional criteria.

Maintenance and Monitoring Considerations

Where transit agencies plan to maintain their own SCADA and communications assets, comprehensive training during the acceptance period as well as a support period can ensure the transit agency can effectively maintain the new system or equipment. Key staff should be provided with hands-on training, covering each inspection procedure, tests and diagnostics, and maintenance procedures. Trainings should use final manuals and instructions and should occur in the regular work stations. For many systems, it is possible to replicate the system architecture in the maintenance facility so that serviced components can be easily tested before being redeployed. For example, railcars and buses commonly use a cart with a radio communications setup identical to that on the vehicle (known as a “bus in a box”). Such equipment, along with high-quality training, can raise the number of parts serviced on-site and can reduce the number returned to the vendor for servicing. On-site maintenance can improve the system uptime and reduce the need for spare systems and components. Simpler system architectures and modular components can help reduce the maintenance skill required to perform most maintenance. Transit agencies may be able to shift more technical maintenance of modular equipment to the vendor.

Similar to security systems, communication system components are often low cost and cheaper to replace than maintain. Specification of high reliability standards in equipment warranties places the risk on the manufacturer and can help ensure minimal reactive maintenance and replacement. Because of the operational importance of communications systems, the extra cost of more reliable equipment may be offset by the resulting lower failure risk. Commercial off-the-shelf products can often bring acceptable reliability at low cost, but transit agencies should test products to confirm they meet acceptable levels prior to wide deployment.

With communication systems and other technology systems, transit agencies may find it helpful to collaborate with the vendor to address quality issues as they arise. Sharing equipment reliability data with the vendor can help understand and better address failure modes. It has been observed that this open communication between asset owners and vendors can result in better equipment performance. Ongoing diagnostics support can be included as a selection criterion for systems procurements.

Capital Rehabilitation and Replacement Considerations

The main reasons for equipment replacement are obsolescence and failure. Relatively short technology lifecycles obviate the need for rehabilitations. However, transit agencies can ensure they use an architecture that allows partial replacement, focusing on system elements with shorter technology lifecycles. For example, transit agencies often opt to undergo a partial replacements or a “hardware refresh” of their radio communications systems. This approach is common for vehicle-based communications equipment where these systems’ useful lives—based on fleet needs and technology obsolescence—do not necessarily coincide with the vehicle lifecycle.

Condition Assessment and Performance Monitoring

Like for security systems, communications and SCADA systems condition and performance monitoring focuses on reliability engineering. Asset owners work to ensure the systems meet reliability standards and track failure patterns. Since technology lifecycles—the interval at which new generations of systems technologies are introduced—typically outpace design life, asset owners must determine when it is cost effective to upgrade these systems. New features and increased demand from system users (that is, for more data bandwidth) usually drive replacement cycles. Hard-line communications systems such as fiber-optics are expected to be upgraded before the end of their effective useful life and require minimal maintenance and monitoring. **Table 5-5** gives some examples of metrics to track ongoing performance of communications, monitoring, and SCADA systems.

Table 5-5. Communications, Monitoring, and SCADA Systems Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Communications/Monitoring/ SCADA	▪ Spare parts availability ▪ Fail-safe design ▪ Obsolescence rate ▪ Percent of asset beyond design life	▪ Reliability (measured in down time or mean time between failure) ▪ Design redundancy ▪ Availability ▪ Coverage ▪ Capacity

Communication systems typically have some level of automatic diagnostics capabilities in place. For instance, most of the communications devices along the guideway network are supervised and monitored through the SCADA system. SCADA data output can be used to analyze failure trends. Vehicle maintenance staff typically maintains vehicle-based communication systems and can access available diagnostics for performance analysis. For the SCADA system itself, as well as for train control systems, much of preventive maintenance involves detailed inspections to identify emerging performance issues in components so that they can be addressed to prevent a service outage. Since SCADA systems have high reliability levels, frequent inspections are likely not cost effective; rather, the agency should take a risk-based approach, using criteria-based prioritization and focusing on units controlling key systems and locations for more frequent inspection.

LA Metro s Indefinite Delivery and Indefinite Quantity (IDIQ) procurement approach allows them to indirectly standardize their communications system equipment (not by design specification but by procurement approach), avoid stocking of their inventory of spares, and exercise just in time orders.

5.2.5 Revenue Collection

Fare collection systems include the point-of-sale machines and collection devices that distribute and collect the transit agency's fare products, as well as the supporting infrastructure. Fare collection may include some combination of or variation on cash fares, ticket fares, and electronic fares, meaning fare collection systems may include heterogeneous elements. Asset management considerations for fare collection include (1) the location of the system components (on the revenue vehicle, in a station, or as part of the back office), (2) the fare collection media being used, and (3) the management of the system, which may cover multiple modes and transit agencies with different fare policies and business rules. The following section outlines lifecycle management considerations for the design, preventive maintenance, replacement, and disposal of fare collection systems.

Design and Procurement Considerations

When possible, transit agencies may wish to avoid over-specifying the fare collection system. Specifications are often most effective when they focus on functional requirements that are technology neutral. Open payment fare collection systems have the advantage of relying less on proprietary software and systems, reducing the chance of a transit agency becoming captive to a single contractor. With proprietary systems, there is also often less operational flexibility built into the system, and lifecycle costs can increase with change orders and modifications. The greatest influences on future transit agency revenue collection systems may come from adopting innovation from other industries, especially with rapid innovation in the financial services sector. Some vendors are expressing a willingness to provide fare collection infrastructure for open payment solutions in order to generate revenue from ongoing operations and transaction revenue, which would remove lifecycle management considerations for many fare collection assets.

Most large transit agencies are migrating to smart card or open payment systems. These options do not necessarily have lower lifecycle costs because transit agencies may need more ticket vending machines or other point-of-sale devices and they require additional wireless infrastructure. They can save on lower overhead from better accounting, lower transaction costs, and easier revenue collection. If carefully set up, they can also collect critical passenger use data. With open payment systems, there may be some savings with respect to equipment customizations, upgrades, and replacements since non-proprietary systems allow competitive bidding. For fare collection systems serving multiple transit agencies or divisions, the procurement should consider the system's flexibility and ability to accommodate diverse business rules, vehicle configurations, and fare products.

The procurement of a fare collection system is also an important opportunity to revisit and reassess existing fare products and business rules for fare collection. New generations of fare collection technology may support schemes that would previously have been infeasible. For instance, GPS technology may support zone-based or distance-based fares on buses. Conversely, if transit agencies maintain their existing complex business rules, they may incur substantial additional implementation costs. A systems engineering approach with a robust concept of operations can identify such implementation issues and help transit agencies improve both their fare policy and their new fare collection system.

Fare collection equipment can be a bottleneck in passenger travel. Ticket vending machines, faregates, and on vehicle fareboxes or electronic tagging all have associated average transaction times. In specifying a system, transit agencies must carefully consider the balance among transaction times, assets to be deployed, and fare enforcement. Easier to use and better monitored systems can raise the fare compliance rate. Faster transaction times may reduce the number of fare collection devices needed. Fare collection system procurements are opportunities for transit agencies to rethink their fare products to improve the passenger experience, collect better data, and improve yields. A systems engineering approach, including significant planning, can yield a superior end product more closely fitting an agency s needs and capabilities.

Especially for revenue collection systems with high levels of proprietary technology, transit agencies should be aware of the technology's lifecycle. Systems early in the product lifecycle may have unproven elements that will require additional change orders and modifications from what a transit agency might otherwise expect. A system later in the product lifecycle can suffer parts shortages later on, interoperability issues with other systems and equipment upgrades, and a lack of key functionalities. Risk analysis exercises in the procurement process can help identify such strategic issues and ensure the selection of an appropriate system and management of potential shortages.

Maintenance and Monitoring Considerations

Transit agencies should plan for a target level of availability and have a maintenance plan in place with scheduled maintenance for fare collection devices. All fare collection systems interface with transit customers and receive high levels of use. While most ticket vending machines and faregates are designed for high reliability and exposed environments, most require some level of preventive and reactive maintenance, and transit agencies should expect these needs to grow over the asset's lifecycle. Fare collection system outages directly affect revenue and should be monitored closely. With planning and experience, agencies can develop and improve response procedures for outages to minimize down time.

For agencies running multiple modes or for regional fare systems, it is important to define responsibility for fare collection elements and ensure that operators and maintenance workers have the necessary knowledge to properly operate and maintain the system. Fare collection systems may be scattered across locations and divisions within a transit agency. If maintenance responsibility is distributed, asset ownership should be clear, and there should be a quality assurance and quality control program in place to ensure a minimum acceptable level of service. Managers responsible for fare collection need visibility into maintenance and metrics, like availability by mode, division, agency, or maintenance facility.

Capital Rehabilitation and Replacement Considerations

Rehabilitation of fare collection equipment may be necessary to achieve its full useful life. Ticket vending machines (and faregates, in particular) receive heavy use and frequently need rehabilitation. If transit agencies expect to have to rehabilitate equipment, they should plan to ensure an adequate supply of parts through the product's lifecycle. They may need to consider whether such work is best completed in-house or through a vendor or the orginal manufacturer.

The City of Phoenix is the only major transit agency that developed a farebox rehabilitation program that resulted in the sales of spare fareboxes to other agencies; however, Phoenix discontinued this program more than a decade ago.

Transit agencies may use rehabilitations to upgrade technology with the intent of improving reliability, preparing for a fare medium changeover, or accessing new features. Transit agencies should carefully consider how such rehabilitations support the overall product lifecycle and try to quantify their value versus other options, such as a total system upgrade.

Condition Assessment and Performance Monitoring

Fare collection equipment availability and reliability are critical metrics to track. Their performance directly determines a transit agency's revenue. Electronic fare collection failures are frequently caused by software rather than hardware issues. Software issues should be closely tracked with a prioritization process in place to address issues. Transit agencies should ensure vendors are accountable for software performance and provide low-risk software support (for instance, through a fixed support fee rather than through charges for individual work orders). **Table 5-6** provides examples of diverse metrics for monitoring fare collection system performance.

Table 5-6. Fare Collection Systems Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Fare Collection	▪ Time between failures ▪ Reliability ▪ Percent of assets beyond design life	▪ Availability of vehicles for revenue service ▪ Fare evasion ▪ Accuracy (fare calculation, accounting/settlement) ▪ Lost fare revenue ▪ Fares unaccounted for (lost transaction data)

Quality control can be an important issue for fare collection systems. Effective operation often requires coordination of operations, maintenance, and back-office staff. Strict adherence to operating protocols for the system can prevent system errors and the resulting loss of fare revenues. Likewise, system upgrades such as new firmware or fare definitions should be carefully tested to ensure they do not create any inadvertent issues that affect the system's operation or stability or create loopholes creating incentives for fare avoidance.

5.3 Industry Standards

The following list outlines any industry standards associated with the lifecycle of the systems asset class:[64]

- **Security**
  - Federal Transit Administration (FTA) Safety and Security, Chapter 9 – Security Systems Integration: Provides design considerations for integrating security systems by discussing methods and tools, and integration from the point of view of the decision-maker and an agency's system development management process.[65]
  - American National Standards Institute (ANSI) Workshop on Transit Security Standardization: the workshop identifies gap and needs for international standards of public transit security, culminating in a

[64] This supplement defines industry standards as requirements, standards, or guidelines that exist currently or are pending.

[65] http://transit-safety.volpe.dot.gov/security/securityinitiatives/designconsiderations/CD/sec9.htm

set of recommendations for developing standards. The workshop focused on four topic areas: physical security, command and control, sensor integration, and communications.[66]

- Transportation Security Administration (TSA) Security and Emergency Management Action Items for Transit Agencies: To increase the security baseline, 17 action items were identified, covering areas such as management and accountability, security and emergency response training, and security program audits. These action items address risks and gaps in security and emergency preparedness that need to be closed.[67]
- National Academies Transportation System Security: Studies, reports, guidelines, and practices on general transportation and surface transportation security.[68]
- National Institute of Standards and Technology "Guide to Industrial Control Systems (ICS) Security": Includes security standards for SCADA and other control systems.[69]

- **Traction Power Electrification**
  - 2012 National Electrical Safety Code: This standard covers safety provisions for hazards that may arise from installation, operation, or maintenance of electric supply stations or overhead and underground electric supply and communication lines.
  - National Fire Protection Agency (NFPA) 70, National Fire Protection Agency (NFPA) 70B: NFPA 70 is the National Electrical Code which is used as a benchmark for safe electrical design, installation, and inspection to protect against electrical hazards. NFPA 70B Electrical Equipment Maintenance contains guidelines for developing and implementing an effective Electrical Preventive Maintenance (EPM) program for all types of equipment, including transformers, power cables, motor control equipment, and lighting.[70]
  - National Fire Protection Association (NFPA) 130, International Electrical Testing Association (NETA) Maintenance Test Specifications: NFPA 130 is the Standard for Fixed Guideway and Transit Rail Systems which outlines fire safety protection of underground, surface, and elevated fixed-guideway transit and passenger rail systems. This includes stations, tunnels, emergency ventilations systems, vehicles, emergency procedures, communications, control systems, and vehicle storage areas. NETA Maintenance Test Specifications compiles the field tests available to ensure electrical systems and equipment perform effectively in order to minimize downtime and maximize life expectancy.[71]
  - American Railway Engineering and Maintenance of Way Association (AREMA) Practical Guide to Railway Engineering: Background and overview information of the specific disciplines of railway engineering design. Chapter Nine covers design principles, construction practice, and maintenance considerations of railway electrification.[72]

---

66 http://publicaa.ansi.org/sites/apdl/Documents/News%20and%20Publications/Links%20Within%20Stories/Final%20Report%20from%20WSC%20Workshop%20on%20Transit%20Security.pdf

67 http://www.tsa.gov/what_we_do/tsnm/mass_transit/sec_baseline.shtm

68 http://ssl.csg.org/terrorism/Transportation%20Security.htm

69 http://csrc.nist.gov/publications/nistpubs/800-82/SP800-82-final.pdf

70 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=70# and http://www.nfpa.org/catalog/product.asp?pid=SET170

71 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=130 and http://www.netaworld.org/about-neta/standards-activities

72 The American Railway Engineering and Maintenance-of-Way Association (AREMA) manual with guidelines on Railway Electrification: http://www.arema.org/publications/pgre/

- Institute of Electrical and Electronics Engineers (IEEE) Standard for SCADA and automation systems in substations.[73]

- **Signals/ATC System**
  - Code of Federal Regulations:
    - 49CFR234 - Grade Crossing Signal System Safety and State Action Plans: Minimum standards for the maintenance, inspection, and testing of highway-rail grade crossing warning systems. Also includes standards for reporting system failures and requires certain states to develop highway-rail grade crossing action plans.[74]
    - 49CFR236 - Rules, Standards, and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances: Applicable to all railroads, contains comprehensive listing of system components and corresponding rules, standards, or instructions.[75]
  - Institute of Electrical and Electronics Engineers (IEEE) Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements: Standard that establishes performance and functional requirements for a communications-based train control (CBTC) system.[76]
  - American Railway Engineering and Maintenance of Way Communications and Signals Manual: Recommended practices to establish uniformity for the installation, operations, and maintenance of signal systems.[77]
  - American Public Transportation Association (APTA) Manual of Standards and Recommended Practices for Rail Transit Systems - Signals and Communications Inspection and Maintenance: Standards and recommended practices for signal and communication equipment inspection and maintenance.[78]

- **Communications/Monitoring/SCADA**
  - APTA Standard for Radio Communication System Inspection and Testing: A standard for inspecting and testing radio communication systems for transit.[79]
  - APTA Recommended Practice for Securing Control and Communications Systems in Transit Environments: Covers security of SCADA and communications systems.[80]
  - National Fire Protection Agency (NFPA) 70: National Electrical Code which is used as a benchmark for safe electrical design, installation, and inspection to protect against electrical hazards.[81]
  - National Fire Protection Agency (NFPA) 130: Standard for Fixed Guideway and Transit Rail Systems which outlines fire safety protection of underground, surface, and elevated fixed-guideway transit and passenger rail systems. This includes stations, tunnels, emergency ventilations systems, vehicles, emergency procedures, communications, control systems, and vehicle storage areas. [82]

---

73 http://standards.ieee.org/findstds/standard/C37.1-2007.html

74 http://cfr.regstoday.com/49cfr234.aspx

75 http://cfr.regstoday.com/49cfr236.aspx

76 http://standards.ieee.org/findstds/standard/1474.1-2004.html

77 AREMA’s recommended standards that follow ANSI standard requirements: http://www.arema.org/publications/cs/index.aspx

78 APTA Manual of Standards and Recommended Practices for Rail Transit Systems, Volume VI - Signals and Communications Inspection and Maintenance: http://www.aptastandards.com/portals/0/volume6/volume_6_introduction.pdf

79 http://www.aptastandards.com/portals/0/volume6/apta_sc_046_03.pdf

80 http://www.aptastandards.com/LinkClick.aspx?fileticket=MGtGhaNVcd0%3d&tabid=329&mid=1670&language=en-US

81 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=70&cookie%5Ftest=1

82 http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=130

- Institute of Electrical and Electronics Engineers (IEEE) Standard and Recommended Practice for Master/Remote Supervisory Control and Data Acquisition Communications.[83]
- Federal Communications Commission (FCC): The FCC has released a variety of technical standards and rules governing radio communications.[84]
- American National Standards Institute (ANSI): Diverse technical standards for materials, testing procedures, and system architectures for diverse electrical systems.[85]
- International Organization for Standardization (ISO): Telecommunication standards, including radio communications and fiber-optic communications.[86]
- National Electrical Manufactures Association (NEMA): Common standards for electrical systems organized by category.[87]

- **Fare Collection**
  - APTA Manual of Standards and Recommended Practices for Universal Transit Farecards: Includes technical specifications, implementation and management guidance, and security standards.[88]

---

83 http://standards.ieee.org/findstds/standard/C37.1-1994.html and http://standards.ieee.org/findstds/standard/999-1992.html
84 http://www.fcc.gov/encyclopedia/oet-technical-documents
85 http://www.ansi.org/standards_activities/overview/overview.aspx?menuid=3
86 http://www.iso.org/iso/home/store/catalogue_ics/catalogue_ics_browse.htm?ICS1=33
87 http://www.nema.org/Standards/Pages/All-Standards-by-Product.aspx
88 http://www.aptastandards.com/Documents/PublishedStandards/Farecard/tabid/331/language/en-US/Default.aspx

Chapter 6

Sustainability and Asset Management

The American Public Transportation Association provides the following definition for sustainability:[89]

> "Sustainability is about practices that make good business sense and good environmental sense. It is balancing the economic, social and environmental needs of a community. For the public transportation industry, this means:
>
> - Employing practices in design and capital construction, such as using sustainable building materials, recycled materials, and solar and other renewable energy sources to make facilities as 'green' as possible.
> - Employing practices in operations and maintenance such as reducing hazardous waste, increasing fuel efficiency, creating more efficient lighting and using energy-efficient propulsion systems.
> - Employing community-based strategies to encourage land use and transit-oriented development designed to increase public transit ridership."

89 http://www.apta.com/resources/hottopics/sustainability/Pages/default.aspx

Improving sustainability practices can work hand-in-hand with an asset management initiative. While asset management generally focuses on the performance and costs associated with the lifecycle of an asset, sustainability provides the added focus on environmental and social priorities. An agency should consider prioritizing sustainability measures that can improve financial and/or operational performance. As shown in **Table 6-1**, a transit agency can integrate sustainability considerations into each stage of lifecycle management planning: design/procure, use/operate, maintain/monitor, rehabilitate, and dispose/reconstruct/replace.

Table 6-1. Example Sustainability Practices Integrated in Lifecycle Management Planning

Lifecycle Management Activities	Example Sustainability Practice
Design/Procure	▪ Incorporate technologies to monitor pollutants continuously ▪ Design for minimal vehicle emissions ▪ Use sustainably sourced materials
Use/Operate	▪ Shift to cleaner fuels
Maintain/Monitor	▪ Monitor air quality to reduce hazmats/pollution
Rehabilitate	▪ Same as "Design/Procure" category
Dispose/Reconstruct/Replace	▪ Dispose of waste responsibly ▪ Focus on reduction/reuse/recycling of waste

This section focuses on four general asset management strategies to support sustainability:

1. Using resources more efficiently
2. Managing waste responsibly
3. Supporting and developing healthy spaces
4. Planning for climate change adaptation

This section outlines considerations for transit agencies to implement the four strategies described above. A focus on these strategies throughout the lifecycle management process can help to realize environmental improvements throughout an asset's lifecycle, including energy savings, cost savings or effectiveness, health improvements, and minimization of greenhouse gas emissions. APTA has several sustainability resources for public transit agencies that address many of these topics in greater depth.[90]

6.1 Resource Efficiency

When transit agencies use resources (fuel, electricity, water, construction materials, and parts and components) efficiently and responsibly, they improve their financial and operational performance, reduce their consumption of non-renewable resources, and reduce their environmental impact. Resource efficiency includes both of the following:

- Rate of use of resource inputs – A lower level or rate of use of energy, water, or other resources translates to a smaller environmental footprint.

[90] http://www.apta.com/resources/hottopics/sustainability/Documents/Transit-Sustainability-Guidelines.pdf
http://www.apta.com/resources/hottopics/sustainability/Documents/Transit-Sustainability-Practice-Compendium.pdf
http://www.apta.com/resources/hottopics/sustainability/Documents/Guidelines-for-Climate-Action-Planning.pdf

- Source of resource inputs – Use of a more sustainable resource (for example, hybrid-electric instead of diesel fuel for power) reduces the environmental footprint, especially greenhouse gas emissions.

During the design and procurement phase, transit agencies can address resource efficiency by designating performance criteria in the design or technical specifications. The specification should allow a straightforward analysis and scoring of lifecycle resource consumption, comparable across scenarios and facility, system, or technology options. The following presents models and standards available to support resource efficiency during design:

- Models such as the APTA methodology for quantifying greenhouse gas emissions[91] are available to compare scenarios for vehicle purchases, focusing on the type of fuel used and the use rate. Standards such as California's Low Carbon Fuel Standard[92] can provide a simpler basis for comparison of fuel and electricity options.
- Frameworks like the U.S. Green Building Council's LEED certification provide a basis for comparison of facility designs, which scores building construction and operation energy efficiency but on other sustainability and resource efficiency measures as well.
- Some models exist for measuring the sustainability of pavement and other civil infrastructure, but for transit, most lifecycle resource efficiency measures focus on construction emissions and the use of cement as a building material.
- For structures and components, more durable and reliable designs can have a sustainability advantage since they need less frequent replacement. Focusing on product lifecycle analysis, reliability, and lifecycle costing can help address this aspect of sustainability.
- The U.S. Environmental Protection Agency's EnergyStar certification is an example of a standard for the comparison of the energy efficiency of building systems. Transit agencies can use similar standards as part of technical specifications for systems procurements.

Transit agencies must understand the extent to which greater efficiency is cost-effective. For assets that consume resources like energy and water, their efficiency is usually offset to some extent by the higher cost of technology. Conducting total lifecycle analyses for different engine technologies will help agencies compare costs, develop exhaust profiles, and ultimately make more informed decisions. A total lifecycle cost analysis focuses on direct costs to the transit agency, while a sustainability lifecycle analysis considers a wider scope to account for both internal and external costs.

Sound Transit in Seattle, Washington has implemented an Environmental and Sustainability Management System (ESMS) that is certified to the ISO 14001 standard. Under this system, the agency is held accountable for identifying environmental impacts and setting objectives and targets for controlling the impacts.

During the operations, maintenance, and rehabilitation phase of an asset lifecycle, the focus shifts from inputs and design to ongoing performance improvement. A data collection framework and a performance improvement process need to be in place in order to evaluate ongoing resource efficiency. An environmental management system (EMS) is the standard data collection and performance improvement framework. It is typically a specification for integrating sustainability program data collection and business processes across existing management control systems rather than in a separate system. An EMS ensures the measurement of key

91 http://www.apta.com/resources/hottopics/sustainability/Pages/default.aspx
92 http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

environmental and sustainability factors to provide visibility into the organization's performance against its sustainability goals. For resource efficiency, performance metrics might include the following:

- Total energy, water, and fuel use
- Unit energy, water, and fuel use (per facility and vehicle service hour)
- Alternate fuel/energy share of fuel/energy use.

The International Standards Organization ISO 14000 standard is a commonly used framework in transit and other industries and includes guidelines for development of an EMS. The ISO 14000 involves (1) the establishment of a baseline of performance and practices, (2) implementation of environmental and sustainability management practices, (3) ongoing monitoring of the implementation program, and (4) a QA/QC and performance improvement process. Such a framework helps a transit agency to implement sustainability tracking and reporting within their existing performance framework to understand and track resource use as part of a process to improve efficiency over time.

6.2 Standards and Regulations

Local building ordinances, which stations or facilities may be subject to, increasingly stress energy and water conservation and efficiency goals. Many municipalities with climate action plans focus on energy and water conservation, as well as energy and water efficiency as critical actions for collective improvement. These actions focus on retrofits as well as new construction. The following is a list of standards and regulations pertaining to the efficient use of resources:

- Executive Order 13514: Federal Leadership in Environmental, Energy, and Economic Performance is a comprehensive fleet management handbook that identifies methods to meet and exceed federal fleet requirements, including reduction strategies for petroleum and greenhouse gas emissions.[93]
- California Low Carbon Fuel Standard is a response to Executive Order S-1-07, which calls for a reduction of at least 10 percent in carbon content of California's transportation fuels by 2020. The order instructs the California Environmental Protection Agency to coordinate with the University of California, the California Energy Commission and other state agencies to develop a compliance schedule to meet the target.[94]
- APTA Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit provides guidelines to transit agencies for quantifying greenhouse gas emissions and strategies for the reduction of emissions.[95]
- LEED for Existing Buildings Rating System measures operations, improvements, and maintenance of existing buildings on a consistent scale in order to maximize operational efficiency and reduce environmental impacts.[96] Other ratings systems include New Construction and Neighborhood Development.
- Energy Star Guidelines for Energy Management are guidelines that outline an energy management strategy to improve energy and financial performance, based on Energy Start practices.[97]
- The Consortium for Energy Efficiency provides resources and RFP guidance for energy efficiency.[98]

93 http://www1.eere.energy.gov/femp/pdfs/eo13514_fleethandbook.pdf
94 http://www.arb.ca.gov/fuels/lcfs/lcfs.htm
95 http://www.apta.com/resources/hottopics/sustainability/Documents/Quantifying-Greenhouse-Gas-Emissions-APTA-Recommended-Practices.pdf
96 http://www.usgbc.org/DisplayPage.aspx?CMSPageID=221
97 http://www.energystar.gov/index.cfm?c=guidelines.guidelines_index
98 http://www.cee1.org/

- The Building for Environmental and Economic Sustainability (BEES) software uses the lifecycle assessment approach to measure the environmental performance of building products to select materials that are not only cost-effective, but also environmentally friendly.[99]
- The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHARE) handbook contains basic principles used in this industry. The sustainability chapter describes principles, design considerations, and evaluations necessary to design sustainable heating, refrigerating, and air conditioning systems.[100]

6.3 Waste Management

Waste management involves the monitoring, gathering, storage, sorting, and disposal of hazardous and waste materials. Examples of waste materials include used engine oil, vehicle washer runoff, used parts, and construction debris. Most transit waste materials are generated at maintenance facilities as part of the operation, maintenance, and rehabilitation of revenue vehicles and supporting assets, or else at construction sites. Waste materials may be landfilled, recycled, reprocessed, or reused. Landfilled waste uses up finite landfill capacity and may eventually contaminate groundwater. Landfilled waste also buries industrial nutrients that could be recycled for use in place of mined or otherwise extracted raw materials. Lifecycle management practices should address waste management from two perspectives:

- Waste diversion – Maximizing the share of waste re-entering production streams as opposed to final disposal and landfilling.
- Waste reduction – Minimizing the level of waste generated in the first place through more efficient use, better design, and better processes.

Recycling, reprocessing, and reuse of waste materials diverts waste from landfills, reduces resource extraction, and can improve resource efficiency through the supply chain. Waste diversion relies on selection of easily diverted materials and products in procurement and having effective processes in place to ensure all waste ends up in the appropriate waste stream.

Waste reduction and avoidance reduction also rely on selecting low-waste approaches and products as part of procurement and on identifying ongoing ways to reduce materials used in the transit agency's production processes. If an agency has an EMS in place, it should include an established process for waste reduction.

An EMS directs and monitors waste streams from the generation point to disposal, and hazardous materials from the procurement stage to disposal. A mature EMS provides managers with full visibility into waste management and a process for ongoing improvement. Through the proper segmentation and accounting of waste materials by type, source, and disposal costs, transit agencies can identify and address opportunities to improve waste management.

Waste streams may contain hazardous materials at various concentrations and levels of stability that may require special handling, processing, and disposal. Responsible waste management means (1) reducing the volume of such waste materials through improved procurement processes, (2) tracking and properly handling hazardous materials through their lifecycle at the agency, and (3) ensuring these materials enter the proper waste stream for legal and responsible disposal. Managing these waste materials is a critical element of sustainable asset management. This is an activity that should be considered when an asset is first designed or procured and it

99 http://www.nist.gov/el/economics/BEESSoftware.cfm/
100 http://www.ashrae.org/resources--publications/handbook

should be documented in the asset's lifecycle management plan. For waste management, it should cover the following:

- Hazardous materials handling and disposal (for example, solvents, fuel storage tank compliance, and used engine oil)
- Earth or groundwater contamination (for example, contamination uncovered during construction activities)
- Wastewater (for example, from vehicle washing or power washing)
- Stormwater (for example, from yard runoff or construction runoff)
- Required documentation and planning (for example, disposal records and an up-to-date spill prevention and response plan)

Opportunities to improve each asset's waste footprint may exist at each lifecycle stage (**Figure 6-1**).

Figure 6-1. Opportunities to Improve Waste Management During an Asset's Lifecycle

Design and Procurement

- Ensure that the transit agency can return all used vehicle parts and system components to the manufacturer for refurbishment or disposal.
- Include "green procurement" measures in the technical specification to select easily recyclable products and minimize use of materials such as heavy metals that require special disposal measures.
- Ensure contractors use best practices for construction waste management.

Maintain/Monitor

- Implement a reliability-centered maintenance framework to extend asset and component useful lives.
- Implement additional stormwater best management practices at facilities.
- Improve the waste diversion rate by improving the agency's recycling program.

Dispose/Reconstruct/Replace

- Find responsible waste disposal vendors.
- Assess facilities for adaptive reuse opportunities.
- Appropriately remediate any facility contamination.

6.3.1 Standards and Regulations

Waste management regulations affecting transit agencies exist at the federal and state levels and often at the local level as well. Agencies are generally subject to local construction and demolition ordinances for capital projects, and local waste ordinances that regulate the disposal of hazardous or contaminated waste. The following is a summary of waste management regulations:

- The Resource Conservation and Recovery Act (RCRA) contains regulations for both non-hazardous solid waste and hazardous waste.[101] These regulations contain guidelines and requirements for developing and implementing waste management plans and the proper storage and disposal of wastes.
- American Society for Testing and Materials (ASTM) has developed several standards for the process of handling waste, including the collection, transport, processing, and recycling or disposal.[102]
- ISO 14001-2400 lays out a framework to develop environmental management systems so that organizations can monitor and control their environmental impact.[103] Benefits of using such systems include reducing the cost of waste management and savings in the consumption of energy and other materials. ISO 13.030 covers standards for wastes, including solid, liquid, and special wastes, as well as installations and equipment for waste disposal and treatment.[104]
- Standards for Universal Waste Management (40CFR Part 273) consists of regulatory standards for the collection and management of universal wastes, including batteries, pesticides, mercury-containing equipment, and light bulbs.[105]
- The Unified Facilities Criteria (UFC): Selection of Methods for the Reduction, Reuse, and Recycling of Demolition Waste provides guidelines for recovery and recycling of building demolition waste to help determine the most feasible methods to reduce waste material that is disposed of in landfills.[106]
- The EPA's Final Guidance on Environmentally Preferable Purchasing helps agencies identify and purchase environmentally preferable purchasing of products and services to meet Executive Order 13101.[107]
- The EPA's Industrial Storm Water Compliance Monitoring inspections are applicable to three types of facility operations: construction sites, industrial sites, and municipal separate storm sewer systems.[108] The inspections involve reviewing the stormwater permit, records, reports, and the Storm Water Pollution Prevention Plan (SWPP), interviewing personnel of SWPP and facility operations, reviewing and observing best management practices, and sampling stormwater discharges.
- Emerging standards for zero waste, such as the Response and Diversion Index (ReDi) measures the effectiveness of waste program processes to ultimately develop strategies to reuse, recycle, and compost materials to reduce the cost of waste disposal and the amount of waste that is landfilled.[109]

6.4 Healthy Spaces

Healthy spaces refer to the commitment to provide healthy and environmentally friendly passenger facilities, workspaces, and vehicles. Lower pollution emissions, environmentally friendly materials, and cleanliness combine to improve sustainability by offering healthier and more sustainable spaces. Promoting healthy spaces can improve air quality and public health. Prioritizing these considerations in asset management can also improve customer satisfaction, increase ridership, and raise employee productivity and satisfaction.

---

101 http://www.epa.gov/epawaste/inforesources/pubs/orientat/rom.pdf
Nonhazardous Waste: http://www.epa.gov/osw/laws-regs/regs-non-haz.htm
Hazardous Waste: http://www.epa.gov/osw/laws-regs/regs-haz.htm

102 For the full list of standards, see: http://www.astm.org/Standards/waste-management-standards.html

103 http://www.iso.org/iso/iso14000

104 http://www.iso.org/iso/home/store/catalogue_ics/catalogue_ics_browse.htm?ICS1=13&ICS2=30

105 http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title40/40cfr273_main_02.tpl

106 http://www.wbdg.org/ccb/DOD/UFC/ufc_1_900_01.pdf

107 http://www.epa.gov/opptintr/epp/pubs/guidance/finalguidance.htm

108 http://www.epa.gov/compliance/monitoring/programs/cwa/stormwater.html

109 https://redi.opp.psu.edu/

The primary opportunity to address healthy spaces is in the design phase. Multiple frameworks exist for evaluating how well facilities investments create healthy spaces. The U.S. Green Building Council's (USGBC) LEED for Neighborhood Development rating system and certification, which combines principles of green building and smart growth, builds on the LEED certification system for buildings, extending it to the neighborhood level. The rating system provides a framework for identifying environmentally friendly planning and design features, construction materials, construction methods, and facilities operation. LEED for Neighborhood Development uses a transparent scoring process that allows development options to be easily compared, and the framework can be easily applied to passenger facilities. The scoring is intended in part to promote development of communities that can be easily served by alternative travel modes, including transit. Transit-oriented development supports higher-quality transit service and higher passenger yields, which can help transit agencies' financial sustainability.

Revenue vehicles are another important area where transit agencies can make decisions in the design phase to support healthy spaces. APTA's Sustainability Guidelines cover rolling stock and includes recommendations for environmentally preferred materials, vehicle comfort and passenger experience, and reduced vehicle emissions. While the EPA sets maximum emissions standards for rolling stock, transit agencies can also refer to other rigorous emissions standards such as those from the California Air Resources Board and the European Union.[110] Transit agencies may also use lifecycle emissions analysis to more effectively support the comparison of alternatives and understand their costs and benefits. Models can provide a framework with which to better evaluate issues such as improved emissions performance but lower fuel economy and varying emissions levels for different pollutants.

Further opportunities to promote healthy spaces exist in the operations, maintenance, and rehabilitation phases. As part of their EMS, transit agencies can use their vehicle maintenance management system to track emissions test results and identify issues and trends with particular systems or vehicles. Examples of how each of these might support healthy spaces is described below:

- Rising emissions may be a sign of a maintenance issue.
- New technologies offer transit agencies the opportunity to monitor some pollutants continuously.
- Vehicle midlife overhauls may offer a chance to install new systems or upgrade components to reduce vehicle pollution, including greenhouse gases like carbon dioxide and nitrous oxide.

For facilities, transit agencies can track indoor air quality with regular tests. Agencies can create a baseline indoor air quality profile and track the profile over time. The EPA's *Building Air Quality: A Guide to Building Owners and Facility Managers* provides guidance for developing such a profile.[111] Transit agencies can also mitigate pollution by implementing stormwater management best practices at their facilities and along guideway.

6.4.1 Standards and Regulations

Multiple states, cities, and local municipalities have adopted green building codes, or have set goals for their facilities to reach high-performance design metrics. In addition, there are various emission standards and air quality standards to improve overall indoor and ambient air quality.

- The FTA issued a report titled *Transit Green Building Action Plan* (July 2009) to Congress that noted "FTA has supported these pioneering initiatives by recognizing the costs of green building design and certification as

[110] http://www.arb.ca.gov/msprog/bus/regdocs.htm
http://europa.eu/legislation_summaries/internal_market/single_market_for_goods/motor_vehicles/motor_vehicles_technical_harmonisation/l24282_en.htm

[111] http://www.epa.gov/iaq/largebldgs/pdf_files/iaq.pdf

eligible project costs."[112] While the FTA has not mandated a specific green building policy, its green building action plan emphasizes several activities that will further enhance the delivery of green transit facilities. These codes apply not only to stations, but also to maintenance facilities. In addition, sustainability principles, such as elimination of volatile organic compounds (VOC) and the use of recycled or biobased materials can be incorporated into other infrastructure elements, such as platforms and canopies. Municipalities have also begun adopting policies, codes, and plans that promote sustainability at the neighborhood or district scale.

- The LEED for Neighborhood Development Rating System integrates smart growth, urbanism, and green building principles. The system is organized into three topic areas: smart location and linkages, neighborhood patterns and design, and infrastructure and buildings.[113]
- The *Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning* is a manual published by the American Society of Heating and Air Conditioning Engineers (ASHRAE).[114] The manual provides guidance for incorporating indoor quality strategies for the design, construction, and maintenance of buildings. ASHRAE has published a standard (62.1-2010) on ventilation for acceptable air quality.[115]
- Building Air Quality: A Guide for Building Owners and Facility Managers is a manual developed by the EPA and the National Institute for Occupational Safety and Health that provides guidance and practices for preventing, identifying, and resolving indoor air quality issues in public and commercial buildings.[116]
- The EPA has compiled regulations and guidance documents for nonroad spark-ignitions (SI) engines over 19 kW, including forklifts, generators, and compressors. Regulations include 40 CFR parts 1048, 1060, 1065, and 1068. These regulations discuss emission standards and certification requirements, exhaust emission test procedures, and general compliance provisions.[117]
- The EPA has compiled a list of diesel programs and regulations for heavy duty highway engines, including 2007 Technical Amendments and several final rules.[118]
- The EPA has compiled a list of resources for controlling emissions derived from passenger cars and light trucks, including Compliance Assurance Program (CAP 2000) and Federal Test Procedure Revisions.[119]
- The EPA has compiled engine testing regulations that comply with the agency's adopted emission standards.[120]
- The EPA's National Ambient Air Quality Standards cover six pollutants considered harmful to public health and the environment: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide.[121]
- The National Menu of Stormwater Best Management Practices covers six topics: public education, public involvement, illicit discharge detection and elimination, construction, post-construction, and pollution prevention/good housekeeping.[122]
- The Greenhouse Gas Protocol Tools is a compilation of various guidance documents for calculating and reporting greenhouse gas emissions; these tools are based on industry best practices.[123] The Corporate Standards manual provides standards and guidance for developing an inventory process.[124]

---

112 http://www.fta.dot.gov/documents/Transit_Green_Building_Action_Plan.pdf
113 http://www.nrdc.org/cities/smartgrowth/files/citizens_guide_LEED-ND.pdf
114 http://www.ashrae.org/resources--publications/bookstore/indoor-air-quality-guide
115 http://www.techstreet.com/ashrae/standards/ashrae/62_1_2010?product_id=1720986
116 http://www.epa.gov/iaq/largebldgs/pdf_files/iaq.pdf
117 http://www.epa.gov/otaq/largesi.htm
118 http://www.epa.gov/otaq/hd-hwy.htm
119 http://www.epa.gov/otaq/ld-hwy.htm
120 http://www.epa.gov/nvfel/testing/regulations.htm
121 http://www.epa.gov/air/criteria.html
122 http://cfpub.epa.gov/npdes/stormwater/menuofbmps/

6.5 Climate Change Adaptation

Transit facilities and infrastructure are vulnerable to the effects of climate change. More frequent and intense flooding from rainfall, rising sea levels, and storm surges can affect the functionality of facilities and guideways and can cause significant damage to them. Heavy snowstorms can cause rail tracks to accumulate ice, stall cars, and have power outages. Wind can cause falling debris to damage overhead catenary systems (OCS). Higher temperatures require materials that have high durability and tolerance, including track, plastics, and electronics. All of these climate effects can put a strain on an agency's infrastructure and disturb normal operations and service, while also having significant cost implications.

Lifecycle costs can be reduced by taking climate risk into consideration throughout an asset's lifecycle:

- **During the design and procurement phase** – Additional costs from repair and retrofit can be prevented later on in the operations and maintenance phase. The cost of mitigation and prevention measures can be significantly less than repair costs once damage has already occurred. As part of a climate adaptation strategy, agencies must use their climate risk assessments to prioritize investments, for instance to ensure their infrastructure and facilities are prepared for higher frequency weather events in order to offset additional risk. Having rigorous technical specifications that take into consideration climate adaptation (such as the temperature tolerance of materials) is a method for agencies to incorporate climate adaptation in their planning process. Resizing of climate control systems may also be necessary to accommodate increasing loads from changing climate. Higher average summer temperatures may require more robust air conditioning in facilities and on vehicles.
- **During the operations and maintenance phase** – The effects of climate change can stress an agency's infrastructure, resulting in more frequent maintenance and repairs, and cause significant delays to service. Maintenance schedules can also be affected by extreme weather events, in which case work must be delayed until conditions improve. Updating preventive maintenance practices and response procedures can help agencies minimize the costs of climate change. In areas increasingly prone to drought, water conservation strategies (such as collecting rainwater and greywater for reuse) reduce water demand and minimize the impact of shortages in drought periods. Likewise, in areas with rising flood risk, agencies should also ensure that stormwater and drainage infrastructure is maintained regularly.
- **During the rehabilitation phase** – Climate adaptation measures can also be incorporated into rehabilitation projects to prevent premature deterioration and prolong the useful life of assets. An agency whose system that experiences frequent flooding may want to prioritize an investment in pervious pavements, which allows water to be absorbed and filtered naturally and prevents runoff from picking up pollutants and degrading water quality.

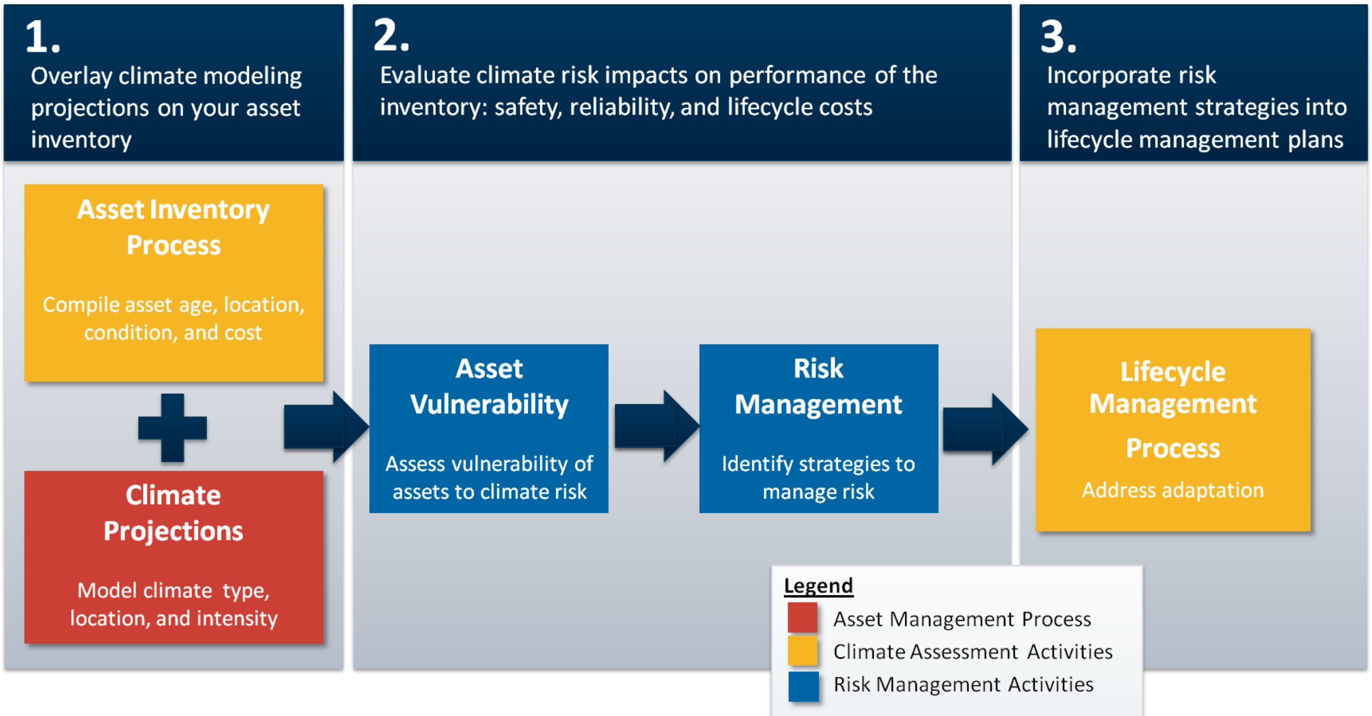
Transit agencies are developing strategies for integrating adaptation actions into their organizational structures and activities. **Figure 6-2** illustrates the process of addressing climate adaptation in an asset management plan. Each of these steps is described in more detail below.

---

[123] http://www.ghgprotocol.org/calculation-tools/all-tools

[124] http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf

Figure 6-2. Addressing Climate Adaptation in an Asset Management Plan

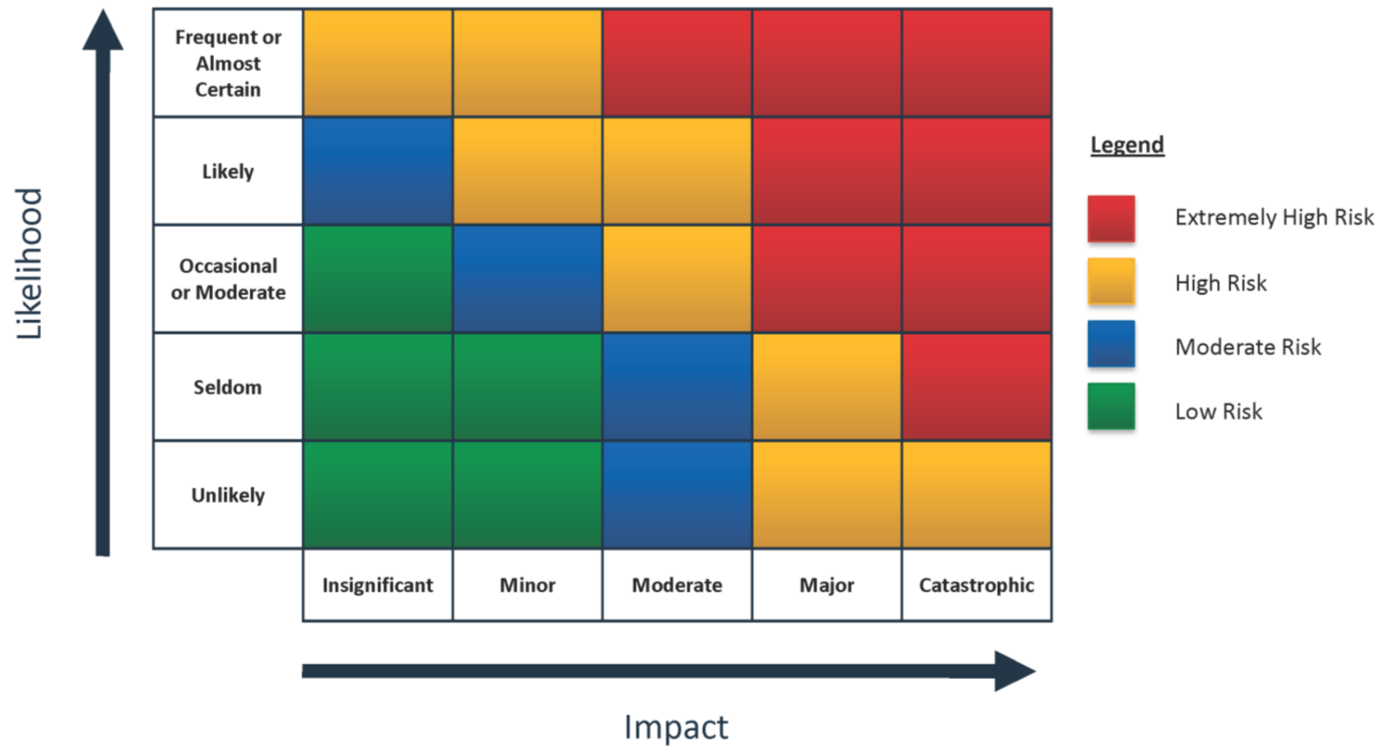


Step 1: A ***climate assessment***, which forecasts and models climate activities (for example, hurricanes, flooding, etc.), is applied at the beginning of the process in conjunction with the ***asset inventory process***. This can help to determine what the climate activities are likely to be and which assets are likely to be affected. As appropriate, this information can be incorporated into the asset inventory.

Step 2: Figure 6-3 is a generalized risk matrix where asset risks are evaluated for their ***asset vulnerability***, which is based on likelihood of occurrence and the level of impact. Likelihood can be defined as the probability that climate hazard will occur and will affect a transit system over the lifetime of the asset; vulnerability is a function of an asset's exposure to climate hazards, sensitivity to those hazards, and the capacity by which an asset can adapt to such hazards.[125] The level of impact depends on the cost of damage, disruption to service and operations, and safety risks. For instance, shorter flood recurrence intervals will not affect properly drained track and facilities outside of existing floodplains. Likewise, a transit agency would likely prioritize higher flood risk at a core system location relative to a peripheral location that does not have a major systemwide dependency.

[125] http://www.fta.dot.gov/documents/FTA_0001_-_Flooded_Bus_Barns_and_Buckled_Rails.pdf

Figure 6-3. Risk Analysis Matrix



Once a detailed assessment is conducted, agencies can continue the ***risk management*** process to develop a project list that can be prioritized and categorized based on risk scoring. Agencies can then identify key upgrades which mitigate these risks. For example, New York's Metropolitan Transportation Authority (MTA) is developing a decision-making matrix to identify mitigation options for protecting vulnerable infrastructure. The matrix incorporates two components: the value of the asset and the level of risk faced. An asset is considered high value if it has an essential role in sustaining systemwide service; a high risk asset is susceptible to a high number of vulnerabilities.

Step 3: This process will reveal which assets are most vulnerable to climate risk and allow the agency to prioritize projects and identify strategies to mitigate these risks. These strategies are subsequently incorporated into the ***lifecycle management plan*** to address how assets can be adapted to face extreme climate events. **Table 6-2** depicts how climate risks can affect each phase of the lifecycle management process.

Agencies are turning to the use of geographic information systems (GIS) to create maps that model climate change projections (such as sea level rise and high temperatures) to help visualize risk. The California Department of Transportation has partnered with the University of California, Davis, to prepare maps to identify hot spots, areas most susceptible to climate change. Information from these maps will help develop guidelines for an adaptation plan to address these risks. The maps will use current sea level rise data as well as data from the National Academy of Sciences ongoing Pacific Coast Sea Level Rise Assessment. New York s MTA used GIS to map out station elevations and evacuation zones, which were used to inform residents of flooding risk during Hurricane Irene in August 2011.

Table 6-2. Managing Climate Risks in the Lifecycle Management Process

	Lifecycle Management Phases			
Key Climate Change Adaption Strategies	**Design/Procure**	**Operations and Maintenance**	**Rehabilitation**	**Asset Classes Covered**
Temperature Tolerance – Specifying and procuring assets to better withstand higher temperatures	✓		✓	▪ Vehicles ▪ Facilities ▪ Guideways ▪ Systems
Water Conservation – Reducing transit's water footprint in response to reduced water availability	✓	✓	✓	▪ Facilities
Weatherproofing – Maintenance and retrofitting to prepare for severe weather events	✓	✓	✓	▪ Facilities ▪ Guideways
Climate Control – HVAC sizing to accommodate changing loads	✓		✓	▪ Vehicles ▪ Facilities

6.5.1 Standards and Regulations

The FTA has launched a major initiative to pilot adaptation programs and projects. The current FTA Policy Statement on Climate Change Adaptation states the following:

> "The Federal Transit Administration (FTA) will integrate consideration of climate change impacts and adaptation to the extent practicable into the planning, operations, policies, and programs of the agency in order to ensure proper stewardship of the federal investment in public transportation systems, for the safety of the traveling public, mobility, and to maintain a state of good repair. FTA is committed to adaptation planning to address the challenges posed by climate change."[126]

The FTA recognizes that public transportation is vulnerable to the impacts of climate change and must be positioned to serve an important role in providing mobility as communities adapt to climate change and providing evacuation services during extreme weather events. The FTA is coordinating with other agencies on climate adaptation planning programs and operations and has also provided grants to support the climate adaptation planning process. The grants offered in the 2011 pilot program focused on systems and services to assess vulnerability and development of adaptation strategies, and the linkage of those strategies to organizational structures and activities.

Many states have incorporated climate adaptation strategies in planning for the needs of the future. California adopted the *2009 California State Adaptation Strategy*, which outlines processes of adaptation for changes in the environment, economy, and society.[127] The plan calls for the incorporation of vulnerability assessments into the current decision-making process, the development of design standards to minimize climate change risks to

[126] http://www.fta.dot.gov/documents/Final_FTA_Policy_Statement_signed_5_31_11.pdf

[127] For the full document, see: http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy.pdf

transportation infrastructure, and incorporation of climate change impacts considerations into disaster preparedness planning.[128] Florida has not adopted a statewide climate adaptation plan, but climate considerations have been incorporated in both its *2060 Florida Transportation Plan* and the *2012 Strategic Intermodal System (SIS) Strategic Plan* to develop decision-making tools and evaluate at-risk infrastructure. Florida Department of Transportation's (DOT) adaptation strategy reflects a broader asset management framework; the state investment policy prioritizes funding preservation needs above capacity improvement.[129] The agency focuses on meeting established preservation and maintenance standards of its roadways and bridges.

The Los Angeles County Metropolitan Transportation Authority (LA Metro) has incorporated climate change adaptation needs to its design criteria for bus and rail projects and has used its environmental management system as a tool to manage climate change. LA Metro has also embraced asset management by incorporating design elements to make its system more flexible, decentralize asset storage, and identify flood prone areas early in the planning process. The agency planning in the present to prevent severe consequences in the future.

128 http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy.pdf
129 http://onlinepubs.trb.org/onlinepubs/circulars/ec152.pdf

APPENDIX

B

Transit Asset Management Maturity Agency Self-Assessment

An interactive version of the Self-Assessment tool on the following pages can be accessed at:

http://www.fta.dot.gov/documents/FTA_Report_No._0027_Self_Assessment.xlsm

Enterprise-Level Questions

Note: You must provide a response for each question, unless it is automatically populated. Select your response from the drop-down menus.

	Score
1. Policy For more information about the role of asset management policy, review Section 3.1.1 of the Asset Management Guide.	
1.1. An agency-wide asset management policy is in place to support the establishment of asset management vision and goals and implementation of an asset management strategy.	
1.2. The agency-wide asset management policy is reviewed and adopted by the executive team or senior management. The asset management policy is regularly evaluated, evolved, and communicated.	
1.3. The asset management policy is clearly linked to / explicitly supported by the agency's overall strategy and planning and to key business processes.	

2. Strategy - For more detail on the role of asset management strategy, see Section 3.1.2 of the Asset Management Guide.	
2.1. An asset management strategy is in place and provides sufficient information, direction, and accountabilities to support the implementation of the asset management policy.	
2.2 .The asset management strategy is in place and outlines asset-specific outcomes and provides high-level direction and expectations for asset management by asset class and functional managers.	
2.3. The asset management strategy is clearly linked to / explicitly supported by the organization's business processes.	
2.4. Agency-wide asset management strategy and goals are reviewed and adopted by the executive team or senior management.	

3. Business Plan For more on the role of Asset Management Planning, see Sections 3.1.3 and 5.4 of the Asset Management Guide.	
3.1. Detailed asset management activities, roles and responsibilities, resources, and timelines are clearly outlined in an Asset Management Plan.	
3.2. The Asset Management Plan clearly establishes levels of service, performance standards, and reporting.	
3.3. The Asset Management Plan is communicated internally, as well as to external stakeholders.	
3.4. The Asset Management Plan is updated regularly, reviewed and adopted by the executive team or senior management.	
3.5. Performance management activities are identified, documented, and implemented.	
3.6. A comprehensive risk assessment and management program is in place.	

4. Inventory For more on the role of asset management inventorying, see Sections 3.2.1 and 4.2.1 of the Asset Management Guide.	
4.1. Assets are classified into maintainable units, which are organized into an asset hierarchy that best supports the agency's business process requirements.	
4.2. The agency has a centralized inventory for storing asset data or multiple inventories with a unique identifier for each asset. The inventory includes data (with clear data definitions) to support key asset management business processes.	
4.3. The inventory is mostly complete and accurate (with minimal assumptions for non-critical assets).	
4.4. Data maintenance and upkeep practices are well-documented and followed. There is a high-level of confidence in critical asset data.	

5. Condition Assessment and Performance Monitoring For more on the role of performance monitoring, see Sections 3.2.2, 4.2.2, and 4.2.3 of the Guide as well as the Asset Class Supplement.	
5.1. Condition is measured consistently across all asset classes and in a way that supports all appropriate business processes.	
5.2. A condition inspection/monitoring program is in place for all asset classes. *Calculated from Asset Class-Level Questions*	0.00
5.3. The level of resources expended to gather condition data is commensurate with the level of risk or uncertainty associated with the asset class. *Calculated from Asset Class-Level Questions*	0.00
5.4. Condition and performance benchmarks and targets are established and monitored to ensure an acceptable level of service for assets and to provide a basis for performance improvement. *Calculated from Asset Class-Level Questions*	0.00

6. Lifecycle Management Planning For more on the role of lifecycle management planning, see Section 3.2.3 of the Asset Management Guide as well as the Asset Class Supplement.	
6.1. Lifecycle management plans are in place for key assets and include asset condition and performance information that can be used to evaluate performance against agency asset management goals.	
6.2. Lifecycle management plans for the agency's most critical assets (based on risk and financial commitment) are updated regularly to document the lifecycle costs, performance, and risks associated with each asset class. *Calculated from Asset Class-Level Questions*	0.00
6.3. Lifecycle management plans reflect input from staff throughout the agency.	
6.4. Lifecycle management plans outline the investment approach for minimizing the total cost of ownership of the asset throughout its lifecycle, including considerations for design/procurement, development of the preventive maintenance and capital rehabilitation strategy, and disposal. *Calculated from Asset Class-Level Questions*	0.00

7. Capital Planning and Programming For more on the role of capital planning and programming, see Section 3.3.1 of the Asset Management Guide.	
7.1. The capital programming process incorporates "top-down" direction from the leadership team regarding high-level priorities.	
7.2. The capital programming process incorporates "bottom-up" direction from asset owners and department leads regarding capital needs.	
7.3. The capital program adheres to the greatest extent possible to the capital needs identified in assets' lifecycle management plans, which are intended to minimize each asset class' total cost of ownership and maximize its performance.	
7.4. The capital program is prioritized based on simple, quantifiable, agreed-upon prioritization criteria that demonstrate the link between capital investments and agency outcomes.	
7.5. Capital programming is informed by quantitative decision-making techniques, including predictive modeling, scenario evaluation, and benefit-cost analyses based on past condition and performance data.	
7.6. Capital programming is fully-integrated with O&M budgeting.	

8. Operations and Maintenance Budgeting For more on the role of operations and maintenance budgeting, see Section 3.3.2 of the Asset Management Guide.	
8.1. Maintenance practices from the agency's lifecycle management plans are used to develop the O&M budget.	
8.2. The maintenance budgeting process relies in part on collaboration and coordination with the capital programming team, operations, and other departments as needed to ensure agency and system goals are met.	

9. Performance Modeling For more on the role of performance modeling and asset management, see Sections 3.3.3 and 4.2.8 of the Asset Management Guide and throughout the Asset Class Supplement.	
9.1. Performance modeling is used to optimize assets' maintenance and investments based on risk levels, performance goals, and overall lifecycle needs.	
9.2. Performance modeling is used to determine optimal investment approaches and timing within an asset class. *Calculated from Asset Class-Level Questions*	**0.00**
9.3. For each asset class, reliability modeling is used to support assets' lifecycle planning. *Calculated from Asset Class-Level Questions*	**0.00**

10. Asset Management Information Systems For more on asset management information systems, see Chapter 4 of the Asset Management Guide.	
10.1. Asset management information systems, comprised of an asset inventory, maintenance management system, condition monitoring and detection systems, and other functions, provide appropriate support to asset management business process and capture key data to support reporting, performance monitoring, and planning and decision making.	
10.2. Integrated data and access to historical data enable the agency to coordinate and collaborate horizontally across the organization and support agency-wide goals and performance.	
10.3. A team of qualified system users or subject matter experts are involved in the development, installation, and evaluation of information systems.	
10.4. There is an information systems planning process to guide the development, integration, and update of information systems, including asset management functions.	

11. Enablers Organization and Leadership For more on asset management enablers, including organization and leadership, see Section 5.3.2 of the Asset Management Guide.	
11.1. Roles and responsibilities are defined for all asset management stakeholders, including the Board, Executive Team, Asset Management Program Manager, and line staff, to ensure appropriate accountabilities.	
11.2. Job descriptions are clearly defined, documented, and communicated.	
11.3. The agency has a transparent and focused change management process in place, supported by senior management, to implement organizational changes in support of improved asset management and the agency's asset management goals and vision.	

12. Enablers Skills and Training For more on asset management enablers, including skills and training, see Section 5.2.2 of the Asset Management Guide.	
12.1. General training is available to educate staff on the asset management initiative's scope, benefits, and processes.	
12.2. More advanced training, as well as high quality documentation and supportive business processes, is provided to support staff development and continuous improvement agency-wide.	
12.3. The agency maintains the appropriate expertise and human resources needed to support asset management business processes and activities.	

13. Enablers Communications For more on asset management enablers, including communications, see Section 5.2.2 of the Asset Management Guide.	
13.1. There are effective business processes in place for coordination and collaboration in asset management across teams and departments.	
13.2. Asset management decision making, including capital programming and O&M budgeting, is conducted transparently at all levels.	
13.3. Senior management regularly communicates progress against asset management goals and changes to the policy, vision, and strategy.	
13.4 Staff has the opportunity to provide input and share lessons learned regarding asset management.	

14. Enablers Values and Culture For more on asset management enablers, includingvalues and culture, see Section 5.2.2 of the Asset Management Guide.	
14.1. The agency, especially capital programming and maintenance departments, has developed an awareness and understanding of asset management.	
14.2. Actions and behaviors supportive of asset management are encouraged and incentivized, including collaboration and coordination with other departments and teams.	
14.3. The agency's management and staff embrace the Asset Management Plan, and employees at all levels take personal responsibility for its implementation.	

15. Enablers Project Management For more on asset management enablers, including project management, see Section 5.2.2 of the Asset Management Guide.	
15.1. The agency's project and program management capabilities are commensurate with the scale and challenges of the capital program and the Asset Management Plan.	
15.2. Effective project management standards and procedures exist and are followed to ensure successful delivery of the capital program and the Asset Management Plan.	
15.3. There are ongoing opportunities for project management training and improvement to support the quality of the capital program and the Asset Management Plan implementation.	

16. Enablers Continuous Improvement For more on asset management enablers, including performance improvement processes, see Section 5.2.2 of the Asset Management Guide.	
16.1. Detailed asset performance and maintenance data are used to identify performance issues and opportunities for all assets.	
16.2. Performance improvement programs and processes exist to diagnose performance issues and develop and implement performance improvement measures.	
16.3. Staff members at all levels are empowered and motivated to be innovative and feel ownership over their asset management responsibilities.	

.   i

l Tran i i i i

U.S. Department of Transportation
Federal Transit Administration
East Building
1200 New Jersey Avenue, SE
Washington, DC 20590
http://www.fta.dot.gov/research