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Asset Management Guide Supplement: Asset Category Overviews & Lifecycle Management

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Federal Transit Administration

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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

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13. ABSTRACT

To advance transit asset management, this update to the Transit Asset Management Guide Supplement provides detailed information about asset category organization and current lifecycle management practices. This Supplement provides a detailed framework for managing assets individually, organized by asset class, as well as a portfolio of assets that comprise an integrated system. This Supplement provides a thorough and detailed understanding of the complexities for managing asset categories, providing stakeholders with a broader understanding of the contemporary practices involved in asset management. This Supplement is organized by the asset classes defined in the TAM Final Rule—Revenue Vehicles, Facilities, Infrastructure, and Equipment. It discusses organizational and maintenance approaches as they relate to these four classes, highlighting the connectivity between individual asset management across classes and how it informs the broader agency asset portfolio.

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Abstract

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This Supplement is organized by the asset classes as defined in the TAM Final Rule—Revenue Vehicles, Facilities, Infrastructure, and Equipment. It discusses organizational and maintenance approaches as they relate to these four classes, highlighting the connectivity between individual asset management across classes and how it informs the broader agency asset portfolio.

SECTION 1

Introduction

The Transit Asset Management (TAM) Guide Supplement provides detailed information about lifecycle management practices for revenue vehicles, facilities, infrastructure, and equipment. This supplement expands upon the *Transit Asset Management Guide* (Federal Transit Administration Report No. 0098) updated in 2016 and includes technical information and industry examples for the unique aspects of maintaining transit assets in four categories: Revenue Vehicles, Facilities, Infrastructure, and Equipment.

This document provides information and guidance on the building blocks of asset lifecycle management for each asset category, describing the methods and considerations for managing each major asset class within each category across its entire lifecycle. This information will support the development of an agency's asset class–specific lifecycle management plans while simultaneously enhancing the asset management program.

This supplement serves two main purposes. First, it provides to the individual or team tasked with asset and lifecycle management a thorough understanding of the complexities for managing individual asset categories and classes. Second, it provides to additional stakeholders within a transit agency a broader understanding of contemporary practices and issues involved in transit asset management, organized by asset category.

There is a wide range in the maturity of asset management practices across asset categories and classes. In the United States, there are no authoritative standards of best practice for asset inventories, condition assessment, or performance modeling in the transit industry. This document provides a general characterization of leading approaches for managing across each asset category and class's lifecycle, giving specific examples where possible. Lifecycle management practices outlined and detailed in this supplement go beyond what is required by the Federal Transit Administration (FTA). It is noted throughout the sections what is specifically required for National Transit Database (NTD) reporting and TAM plan development.

Lifecycle Management Practices

Lifecycle management planning is intended to inform long-term planning efforts, financial performance, and efficient service delivery. Effective practices will work to plan and minimize costs associated with procurement, operation, maintenance, rehabilitation, and replacement of an asset while meeting or exceeding established service and reliability commitments for both the individual asset and the transit system as a whole.

This supplement discusses lifecycle management practices for revenue vehicles, facilities, infrastructure, and equipment, organized into four organizational and management approaches:

- **Design and Procurement**, including considerations of how asset design and decisions made prior to operation can have implications for its lifecycle management.
- **Operations and Maintenance**, including how day-to-day operations and larger business practices impact lifecycle management.
- **Rehabilitation and Replacement**, including information on how to make decisions regarding rehabilitation and replacement, affecting an individual asset's useful life.
- **Condition Assessment and Performance**, including how to maintain the information needed to implement effective performance monitoring practices.

Figure 1-1

Lifecycle Management Principles

Transit agencies are responsible for the planning and implementation of lifecycle management for all asset categories. Within an agency, a manager or senior-level staff member is usually in charge of an asset category's maintenance and, ideally, is also involved in the asset's design and procurement. This staff member is responsible for lifecycle management planning, developing and implementing the lifecycle management plan, and facilitating asset management activities. The approaches listed above provide a framework to improve the effectiveness of these lifecycle management activities and thereby improve lifecycle management and optimize asset performance.

Scope of Lifecycle Management Plans

The appropriate level of detail in a lifecycle management plan will vary. The lifecycle management plan can be an effective way to provide asset managers with a comprehensive, concise, and up-to-date summary document of assets or to provide practitioners with thorough documentation of planning and procedures. For example, a facilities management plan—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 four organizational and management approaches, and a mature plan should promote all of the principles laid out in Figure 1. However, an asset category-specific lifecycle management plan can be high level and still comprehensively address the various aspects of lifecycle management planning—for instance, by referencing specific technical documentation such as the vehicle maintenance manual.

Organizational and Management Approaches

The following four organizational and management approaches are used in all four asset categories. They are described below in their relevance to lifecycle and asset management as a whole, with asset category specific information provided in Section 2 through 5.

Design and Procurement

Decisions made during the design and procurement stage are critical to the management of an asset and can impact its useful life and longevity. These decisions consider both immediate and longer-term needs for service, customer usage, and flexibility to adapt to future technologies and energy sources, among other things. By doing so, this incorporates robust risk assessment and quality assurance and quality control (QA/QC) processes into the design and procurement phase, mitigating the likelihood of poor design decisions and identifying potential and actual quality issues before they become the transit agency's responsibility. Whereas the costs for corrective actions are generally lower when early and increase as design and construction proceed, it is still critical to continue evaluating potential risks and QA/QC issues throughout the construction phase to identify other potential challenges to an asset's lifecycle. Decisions made in the design and procurement phase can inform performance monitoring through developing detailed performance specifications that transit agency staff will monitor throughout the asset's life.

Recognizing that many transit agencies are responsible for legacy assets and that circumstances are often dynamic, regular risk assessments can help identify potential issues and provide an opportunity to develop cost-effective mitigation strategies to implement as part of facility renovations or rehabilitations. Identifying potential risk during the design and procurement phase helps to mitigate future issues and reduce cost and not disrupt operations and service provision. Specific considerations for vehicles and facilities can be found in Sections 2 and 3.

Operations and Maintenance

Understanding the complexities of operating and maintaining assets across the four categories is necessary to inform a lifecycle management strategy. Although many operation and maintenance considerations flow directly from decisions made during the asset design and procurement stage, the operations and maintenance phase itself is equally critical in effectively managing transit assets.

Collecting and managing robust maintenance data provides agencies with the necessary information to proactively identify maintenance and operation concerns and test new approaches. These data should inform an agency database that includes prior and planned maintenance so the agency may proactively plan for maintenance schedules, work-order processing, equipment inventories, an updated asset inventory, etc. These data are essential to being able to conduct condition assessments and set targets to monitor asset performance.

Capital Rehabilitation and Replacement

Effectively planning for the rehabilitation and replacement of assets is an essential part of lifecycle management. Asset owners can use a systems-based approach to consider how a particular asset contributes to the larger system of operations, helping to understand whether to rehabilitate or replace an asset and how to schedule or adjust other operations to account for and reduce any resulting disruption in service. This approach includes analysis of potential risks and mitigation as well as performance metrics. Many agencies use a maintenance management system to help optimize the timing and capital planning for rehabilitating or replacing assets.

Condition Assessment and Performance Monitoring

Transit agencies can address facility and vehicle maintainability and expected lifecycle cost through ongoing performance modeling. These considerations begin in the design and procurement stages by developing detailed performance specifications that transit agency staff will monitor throughout the asset's life. 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.

Performance modeling requires an agency culture that supports a holistic view of all assets and an agency-wide commitment to achieving performance goals and targets. These practices ensure accountability for the agency's assets and are best determined and incorporated into business practices. It can be helpful not only to establish formal design review processes for asset 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. Collaboration among the design and procurement teams, the management teams for vehicles and facilities, and the asset's users is critical to take advantage of such opportunities.

Maintenance Approaches

In addition to the primary responsibility of supporting ongoing operations, asset managers also need to balance multiple other needs, including controlling costs and limiting capital expenses and needs, meeting regulatory requirements, and meeting the operator's overall vision.

There are times when it is less expensive or less time-consuming to incur maintenance expenses, even substantial ones, than to purchase new equipment. The decision whether to maintain and use older equipment vs. acquire new equipment is generally known as replacement analysis. Such analysis is conducted by determining the net present value of each of the options (i.e., maintaining and using older equipment, along with various replacement options) using the full costs and benefits over the planning horizon, and selecting the alternative with the highest net present value (or lowest net present costs). Of course, agencies must consider alternatives within the constraints of available funding options.

Transit agencies must also consider maintenance-related requirements imposed by regulatory bodies (e.g., FTA and the Federal Railroad Administration [FRA]) as well as relevant industry standards (developed by groups such as the American Public Transit Association [APTA] or the Association of American Railroads [AAR]), and other relevant State or local requirements. These organizations provide minimum standards for the use of rolling stock, fixed infrastructure, and some other assets; standards may be based on legal requirements as well as industry best practices. It is good practice for transit agencies to maintain not only transit assets but also data management systems to adapt to changing practices and for record-keeping and reporting requirements.

There are four primary approaches to maintaining assets, listed in order of most reactive to most proactive:

- **Replace upon "failure" or run-to-failure or reactive maintenance**, where a component or sub-system is replaced when it fails to perform its function in a safe or effective manner.
- **Interval-based maintenance, or preventive, planned or scheduled maintenance**, where specific maintenance procedures are performed on an asset at specific intervals regardless of condition, typically on a time or usage basis.
- **Inspection-based or condition-based maintenance**, where inspections are conducted frequently enough to more fully consume an asset prior to failure, based on condition or performance results.
- **Predictive maintenance**, which relies on a range of manual and automated inspection techniques, combined with a clear understanding of component lifecycles, to undertake maintenance prior to failure while minimizing premature maintenance actions.

Additionally, Reliability-Centered Maintenance (RCM) is a growing framework in more proactive maintenance that optimizes value, safety, and performance of an asset. RCM involves using root-cause analysis of past events (Failure Modes and Effects Analysis, or FMEA) to optimize an asset's maintenance program by targeting the best strategy (reactive, preventative, condition-based, predictive, etc.) based on the relative probability of a failure and the relative impact of a failure.

The decision to adopt a particular maintenance strategy will depend on economic constraints, performance requirements, asset life and ownership, and the available information that is required to support the selected strategies. Transit agencies may employ more than one of these strategies, depending on the assets and the operational context.

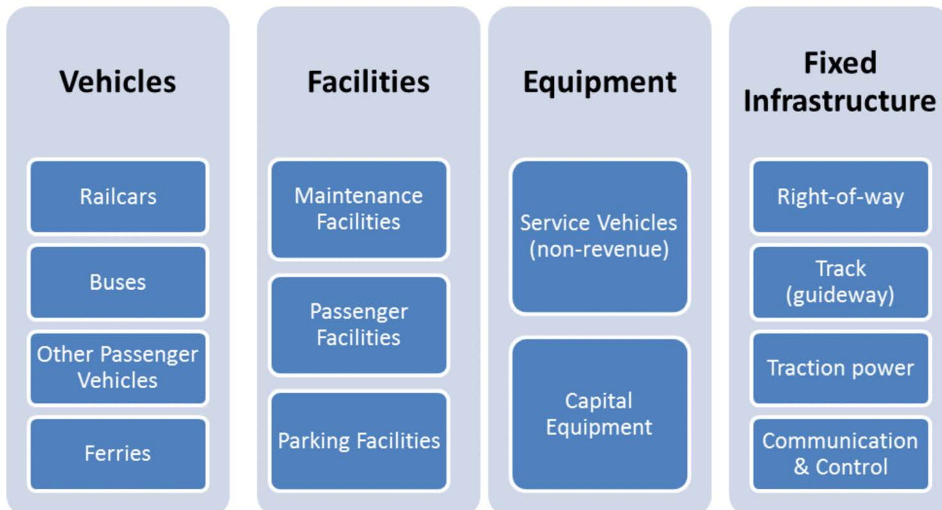
With all types of physical assets, once agencies determine a maintenance approach for each type of asset at the outset, they can develop plans that they review at periodic intervals to evaluate performance and make necessary adjustments. With the increasing availability of real-time performance data, acquisition, and retention of detailed data on maintenance actions, it is possible to more effectively manage an asset throughout its entire lifespan by leveraging a strong understanding of the factors affecting asset performance, and optimizing maintenance to meet the array of performance, financial, compliance, and market requirements.

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. Figure 1-2 provides the organization for the asset inventory that matches the asset class structure in the TAM rule. Facilities and stations are combined into a single asset category to reflect their many shared management practices; components of facilities may be considered infrastructure or equipment.

Figure 1-2

Transit Asset Categories and Classes



FTA requires that an agency TAM plan addresses all major asset classes it owns. This document is organized according to the four asset categories as defined in the TAM rule:

- **Section 2: Vehicles**, including Railcars, Buses, Other Passenger Vehicles, and Ferries
- **Section 3: Facilities**, including Maintenance, Administration, and Passenger Facilities
- **Section 4: Equipment**, including Service Vehicles (non-revenue) and Capital Equipment
- **Section 5: Infrastructure**, including Right-of-Way, Track, Traction Power, and Communication and Control

This supplement does not explicitly address roadway, park-and-rides, and administrative or other buildings whose lifecycle management requirements are not unique to the transit industry. Also, although this supplement includes ferries as an asset category, it does not discuss lifecycle management practices specific to maritime assets. Nevertheless, most of the principles and approaches to lifecycle management planning and implementation outlined in this supplement will apply to these assets.

SECTION 2

Revenue Vehicles

This section offers suggestions for incorporating advanced and improved transit vehicle management practices. These suggestions may be helpful in meeting existing Federal reporting requirements and may result in reduced labor time and costs and more efficient and successful transit service delivery. For definitions of technical terms that are included in this section, see the Glossary.

Table 2-1 provides an example framework or hierarchy with a breakdown of asset types, elements, and sub-elements for each asset class. Although agencies are not required to report assets to NTD at the element/sub-element level, categorizing and inventorying assets down to this granular level may be useful in developing a robust asset management program. Agencies may also find it useful to develop an "Asset Subtypes" category (not shown in Table 2-1) prior to identifying elements/sub-elements. These Subtypes may have different elements and subsequent maintenance and management activities. Since Asset Subtypes are not required, they can be customizable for each agency and can be useful in developing your asset inventory.

This asset hierarchy is changed from that in the previous TAM Guide Supplement. As this section has been refocused to include only revenue vehicles, the non-revenue vehicles outlined in the previous Supplement have been moved to the Equipment section. The revised Rolling Stock Asset Classes' Potential Asset Hierarchy breaks assets into four classes: Railcars, Buses, Other Passenger Vehicles (as used for the provision of transit service), and Ferries.

Table 2-1

Rolling Stock Asset Class Potential Asset Hierarchy

1. Define Asset Class	2. Catalog Asset Types	3. Identify Asset Elements / Sub-Elements
Railcars	• Commuter rail locomotive (RL) • Commuter rail passenger coach (RP) • Commuter rail self-propelled passenger car (RS) • Heavy rail passenger car (HR) • Light rail vehicle (LR) • Streetcar (SR) • Vintage trolley (VT)	• Wheel and axle sets • Power plants and propulsion systems • Braking systems • Heating, ventilation and air conditioning (HVAC) systems • Auxiliary power systems • Transmissions/gearboxes
Bus (Rubber-Tire Vehicles)	• Articulated bus (AB) • Automobile (AO) • Over-the-road bus (BR) • Bus (BU) • Cutaway bus (CU) • Double decked bus (DB) • Minivan (MV) • Minibus (MB) • Rubber-tired vintage trolley (RT) • School bus (SB) • Sport Utility Vehicle (SV) • Trolleybus (TB) • Van (VN)	
Other Passenger Vehicles	• Aerial Tramway (AT) • Automated Guideway Vehicle (AG) • Cable car (CC) • Inclined Plane Vehicle (IP) • Monorail Vehicle (MO)	
Ferries	• Ferryboat (FB)	

Lifecycle Management Practices

This section offers suggestions for implementing new or different asset management practices for revenue vehicles. Although many fleet management activities are comprehensive and successful, there are opportunities for improvement. Vehicle technologies are changing along with rider behavior and passenger expectations (consider the incorporation of electronic payment systems, on-board GPS and Wi-Fi, and alternative fuels in modern fleets).

In addition, new generations of fleet and maintenance management systems continue to offer new capabilities to improve data collection. Increasingly, vehicles are manufactured to collect more detailed operating information and diagnostics, which, in some cases, can be relayed to maintenance and operations departments in real time. An agency with the processes in place to effectively integrate and analyze this growing flow of data can better identify opportunities for efficiency and cost savings and better manage its complex fleet.

This section presents new ideas that decision-makers and planners can incorporate into the lifecycle management process.

For revenue vehicles, these multiple frameworks and suggestions cover four main aspects of fleet management:

- Design and Procurement
- Operations and Maintenance
- Capital Rehabilitation and Replacement
- Condition Assessment and Performance Monitoring

Making Design and Procurement Decisions

Materials Selection

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 features. A vehicle design based on improved modern materials and modular assemblies does not necessarily require the traditional midlife overhaul program.

Additionally, understanding fuel and engine types, and the tradeoffs associated with each, is the single most critical decision to make regarding vehicle materials. Complex analyses of initial and ongoing costs, short and long-term infrastructure needs, fuel efficiency, and environmental impacts, all play a role in the selection process. A strong understanding of how these fuel and engine types will impact agency operations will guide the decision-making process. This process can also offer an opportunity to identify and specify standard elements and parts and explore availability on third-party aftermarkets vs. purchasing directly from the original manufacturer.

Some transit agencies use LED lighting in place of incandescent or fluorescent lighting, which can be more expensive upfront to purchase, but lasts longer and may offer benefits related to space and weight.

In many cases, the manufacturer can be incentivized to undertake such considerations; 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 requirements can be reduced, postponed, or even eliminated and then supplemented or substituted with an element-level targeted overhaul.

Design Review

Thoughtful and comprehensive design review can reduce total lifecycle cost by resulting in procurements of vehicles that are easier to maintain. This process can also improve coordination among departments, with the design review team working with planning and customer teams to understand vehicle size, seating arrangements, and customer amenities, among other features. Design review may include use of a third-party consultant or a special design-review committee composed of cross-functional experts from within the agency.

Some transit agencies use multiple automotive type batteries in lieu of the traditional single (8D type) battery, which is heavy and cumbersome to replace. Consulting with design team members who have substantial maintenance experience early in a project can improve vehicle maintainability through the design process.

For example, maintenance staff involved in the design review process may be able to identify a task that is either difficult to perform for ergonomic reasons, needs more setup time, requires additional protective equipment, or can result in injuries to personnel. Input prior to procurement can decrease the likelihood of unintended impacts later. Design review can also identify pitfalls such as proprietary elements, non-standard vehicle elements, and integrated (vs. modular) systems. Table 2-2 references various design considerations for vehicles and ways to improve the design to reduce lifecycle costs.

Furthermore, when considering the interior design of a vehicle, the agency should consider ridership projects and necessary capacity as well as access to interior lights, panels, and other features and how placement of seats or poles may affect such access.

Table 2-2

Sample Vehicle Design Considerations Affecting Lifecycle Costs

Elements	Typical Design	Improved Design
Light fixtures	Multiple screws	Spring clips, catches, or maintenance key locks
Access panel	Prop rods	Automatic hold-open device (e.g., gas springs)
Overhead access panel	Clip type, safety chains or cables	Spring latch-type catches (e.g., 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 multi-pin plugs

Elements	Typical Design	Improved Design
Threaded fasteners for frequent access items	Bolts, screws, and nuts	Spring clips, over-centered catches, spring latches, and crew-key locks ("tool-less" access or mounting)
General assemblies	Multiple element assemblies – distributed	Unitized or packaged assembles that may be disconnected, removed and repaired off-line
Diagnostics	Connections normally at 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

Long-Term Planning

The revenue vehicle procurement process, which can be expensive and time-consuming, affords agency staff with an opportunity to be strategic about balancing near-term and long-term planning objectives. Long-range, cross-asset planning can help an agency realize economies of scale. Alternatively, procurements that occur outside of comprehensive long-term analyses can have detrimental impacts on an agency's fleet and, ultimately, its service record. Decision support tools, such as customized SWOT (Strengths, Weaknesses, Opportunities, and Threats/Challenges) analyses can incorporate both quantitative data and qualitative assessments to help asset managers enlarge the scope of consideration for better procurement results.

Contracting and Evaluation Methods

The following technical and contractual risk management measures can mitigate risk of unmanageable lifecycle costs:

- **Reliability, Accessibility, Maintainability and Safety (RAMS) demonstrations programs** – RAMS programs can help test a small sample of new types of vehicles to determine that they will be 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.

- **Third-party testing and inspections** – Adding testing and inspections by a qualified third party during the manufacturing process can help identify potential defects that might otherwise surface only years after the vehicle has become operational. For example, vibration within a vehicle contributes to element failure (electrical connections become loose, electrical elements fail, mounting brackets fatigue). Vibration effects can be mitigated within elements by using vibration-resistant designs, multipoint mounting systems, and vibration isolators. One way to improve reliability and lower operational and maintenance costs over the life of the asset is to include vibration testing requirements in procurement and a mandate to implement mitigation factors.
- **Performance- or availability-based maintenance contracts** – Such contracts fix the transit agency's 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. These contracts should include clear, digitalized asset inventory records, maintenance guidelines, and parts inventories so that asset managers within the agency can properly manage the asset. One example of this kind of risk management approach is leasing tires, whereby agencies pay the tire vendor for a tire supply by the mile rather than purchasing tires directly.

Operations and Maintenance Considerations

Collecting and Utilizing Maintenance Data

An effective maintenance management system and data collection process can provide agencies with high-quality data with which to assess their maintenance and safety practices, identify maintenance and safety issues and opportunities, and test new approaches.

Reliability-centered maintenance (RCM) is one framework for performance modeling and improvement, which focuses on reducing costs and improving safety through scheduling preventive maintenance activities to maximize reliability and minimize the probability of an in-service failure. An RCM approach could include:

- Creating a system for coding element failures and onboard vehicle diagnostic messages
- Developing user-friendly data collection forms to be used after a failure
- Tracking details about the failure, including the actual failure mode, the resolution, and any required testing
- Capturing details such as labor time, parts costs, and total repair costs
- Analyzing historical failure data and trend data to develop a preventive maintenance schedule
- Using data for element warranty compliance

Safety considerations are inherent to an RCM framework. Through preventive maintenance, agencies will be able to more effectively predict and limit large-scale safety issues that threaten the system and passenger safety. These effective maintenance management systems and data collection processes can be used to keep vehicles in safe condition, thereby improving passenger experience, workplace safety for operators and maintainers, and the efficiency and reliability of the system by limiting service disruptions.

Business Processes and Management Systems

High-quality business processes and management control systems provide the scaffolding 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 who can identify the root cause of issues and propose alternative approaches. For example, a maintenance management system can help improve scheduling and resource allocation.

The following factors should be considered when developing a preventive maintenance plan:

- Preventive maintenance requirements should conform to manufacturer's recommendations to maintain warranty status.
- Maintenance departments need sufficient qualified human resources/staff.
- Mechanics and technicians will need ongoing training and professional development opportunities.
- The maintenance department must have ample and appropriate on-site diagnostics equipment.
- Parts and materials inventory management is essential to minimizing 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 should coordinate around peak-vehicle availability so maintenance can coincide with a single team's shift.
- Heavy use periods, such as temporary road closures or sporting events, may increase maintenance requirements.

Workforce Improvement

In many cases, the effectiveness of an agency's asset management program rests not on the size of its spare parts inventory or how modern its maintenance database is but on the quality of its workforce. Some ideas to consider for continuously improving and managing a workforce responsible for vehicle management include the following:

- Consider hiring third parties to conduct regular audits of vehicles to ensure that staff are carrying out appropriate maintenance, inspections, and repairs.
- In-house quality assurance inspectors might perform spot-check inspections of repair jobs and element rebuilds.
- Train staff with tools and technologies that can support inspections, maintenance, and work order procedures.
- Provide a common approach and baseline skillset for maintenance staff using 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.
- Invest in knowledge transfer activities and knowledge sharing among agency colleagues and across transit agencies.
- Create maintenance documentation that uses clear language, photos, and diagrams, and examples.
- Use and update electronic maintenance documentation.

Capital Rehabilitation and Replacement Considerations

Following a Systems Approach

Maintenance planners may consider a systems-based approach when defining an optimal rehabilitation process. This includes evaluating a range of tradeoffs related to funding, performance, and system priorities when deciding whether to rehabilitate vehicles versus replacing them. A cost-effective rehabilitation program would:

- Identify appropriate elements for inclusion.
- Evaluate the benefits of refurbishing or replacing vehicle elements.
- Establish an appropriate timeline, with sufficient labor and other resources, while maximizing ongoing vehicle availability.

In some cases, rehabilitation may be fairly comprehensive and include overhaul of body, flooring, undercarriage, powertrain, electrical, and HVAC. In other cases, targeted rehabilitation campaigns are sufficient.

Historical trend data can indicate the need for an area-specific rehabilitation or targeted campaign. Data collection and trend analysis programs can help keep maintenance schedules tied to the documented condition of the elements and avoid down time resulting from the replacement of degraded elements.

It is useful for maintenance planners to outline rehabilitation logistics, including equipment, parts, labor, and facility requirements. Once this information is assembled, an agency can decide if it is more cost-effective to perform the work in-house or through an outside vendor.

Modular vehicle assemblies are one way to reduce maintenance downtime and make targeted overhauls more successful. Modular systems can be removed from a vehicle, overhauled, reworked, or upgraded off-line with fewer impacts on vehicle availability or revenue service. A detailed asset inventory system can be used to track these elements' performance across vehicles.

Note that the maintenance planning model described here may 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.

Maintenance Management System

An effective maintenance management system and qualified maintenance planners can optimize the timing of rehabilitation and replacement. For vehicle elements that might need an overhaul or replacement once or twice (if ever) within the service life 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

Agencies can use a standardized or customized method to assess condition and monitor performance of assets. One standardized approach is the Transportation Economic Requirements Model (TERM), which is based on a 1 to 5 scale.

Table 2-3

TERM Rating Scale

TERM Rating	Condition	Description
5	Excellent	No visible defects, near-new condition
4	Good	Some slightly defective or deteriorated elements
3	Adequate	Moderately defective or deteriorated elements
2	Marginal	Defective or deteriorated elements in need of replacement
1	Poor	Seriously damaged elements in need of immediate repair

Performance monitoring can also be achieved by identifying Key Performance Indicators (KPIs) according to individual agency investment and service priorities. Any number or type of KPIs can be used as long as the indicators are specific, measurable, attainable, relevant, and time-bound.

Collecting and Storing Data

Having a strong data collection infrastructure and accurate asset inventory is the foundation for transit asset management. Trustworthy data not only guide immediate maintenance investments, but historical data help discern important patterns and long-term trends that can inform investments and management activities. Routine data collection activities include:

- Capturing data from scheduled inspections of specific systems and elements
- Collecting daily maintenance data through the vehicle maintenance management system
- Onboard vehicle systems and diagnostics
- Stand-alone sensor systems
- Ad hoc testing and inspections

It can be challenging to make the most strategic and best use of data that originates from multiple systems and multiple users. Transit agency professionals should consider integrating various management systems into a consolidated master database. Open access to data across the organization can allow staff to supplement the visual inspection information in condition assessments.

Selecting the Most Effective Condition Measures and Metrics

Vehicle and element condition measures are used as a benchmark for evaluating the effectiveness of lifecycle management practices and investments. Expanded and improved data collection can facilitate condition tracking, which can improve maintenance scheduling, cost-effectiveness, and long-term capital planning.

To the extent practical, individual condition measures should map closely to the vehicle asset inventory. Condition scores should be a mixture of qualitative and quantitative data and should be linked to a vehicle or fleet's capacity to

For an individual element, 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 service life remains until they must be replaced. Particular thickness ranges are associated with distinct actions, such as immediate repair, scheduled repair, or no action.

meet performance goals. For purposes of funding prioritization, a transit agency may want to use condition measures that are comparable across asset classes.

For an individual vehicle, agencies can aggregate available data into a condition index based on inspections and maintenance records. Using a consistent 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 accounts for 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 two years, allowing easy comparison among vehicles. These scores can help the agency to prioritize vehicles for maintenance and rehabilitation.

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.

Regularly-scheduled condition assessments or inspections will complement the overall preventive maintenance requirements and can help identify any element or system trends that would lead to service deficiencies. More comprehensive condition assessments should take place throughout the life of the vehicle to determine the condition of major elements. These condition assessments are slightly different than the overall inspection performed during routine maintenance because they consider the degradation of performance that would normally occur as elements 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 provides examples of 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

Sample Rolling Stock Measures and Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Revenue Vehicles (All)	• Overall appearance meets established operational criteria • Correct operation of systems, assemblies, and elements • Successful passage of test requirements • Vehicle age • Service age • Service miles • 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 • Number of vehicle safety events (or ratio per service hours/miles)

Inspections

In many cases, the effectiveness of an agency's asset management program rests not on the size of its spare parts inventory or how modern its maintenance database is but on the quality of its workforce. Many agencies use in-house quality assurance inspectors to perform spot-check inspections of repair jobs and element rebuilds, and some also hire third-party inspectors to conduct regular audits of vehicles to ensure that staff are carrying out appropriate maintenance, inspections, and repairs. Considerations for hiring and scheduling inspections include the following:

- Inspectors should work full-time during inspection periods.
- 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.
- Inspections should account for subsequent manufacturing processes and should continually be monitored for content and quality.
- Contract inspectors should be dedicated to one build of vehicles at a time so they can concentrate on one specification.
- Inspectors should have clear procedures and guides, including photographs where appropriate, to ensure consistency across multiple inspections.
- For intake inspections, the inspection should end when the manufacturer offers the completed vehicle to an agency's inspector 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.

Industry Standards

In addition to the suggestions offered in this supplement, several transit and transportation industry groups have created standards for vehicle management.[1]

Rail and Fixed-Guideway Vehicles

- APTA Rail Transit Systems Standards Program – 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]
- *AAR Manual of Standards and Recommended Practices* – includes standards for the design, fabrication, and construction of freight cars, maintenance and rehabilitation, and management practices.[3]
- FRA Office of Railroad Safety – 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) *2018 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 and Paratransit Vehicles

- APTA Bus Transit Systems Standards – includes standards for bus procurement, maintenance and safety, and operations.[7]

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[1] This supplement defines industry standards as requirements, standards, or guidelines that exist currently or are pending.

[2] https://aar.com/standards/publications.html.

[3] Available for purchase at https://www.aar.com/standards/publications.html.

[4] https://www.fra.dot.gov/Page/P0010.

[5] Available for purchase at http://www.arema.org/AREMA_MBRR/AREMA_MBRR/AREMAStore/MRE.aspx.

[6] https://www.access-board.gov/guidelines-and-standards/transportation/vehicles/ada-accessibility-guidelines-for-transportation-vehicles-over-the-road-buses.

[7] https://www.apta.com/research-technical-resources/standards/bus-transit-systems-standards-program/.

- 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 elements 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]

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]
- 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]
- *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]

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[8] https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&ty=HTML&h=L&mc=true&=PART&n=pt49.5.390.

[9] https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&ty=HTML&h=L&mc=true&=PART&n=pt49.5.396.

[10] https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&ty=HTML&h=L&mc=true&=PART&n=pt49.5.393.

[11] https://one.nhtsa.gov/cars/rules/import/fmvss/index.html.

[12] https://www.chp.ca.gov/CommercialVehicleSectionSite/Documents/B%20chp108a.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] https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-heavy-duty-highway-engines-and-vehicles.

[16] https://www.access-board.gov/guidelines-and-standards/transportation/vehicles/ada-accessibility-guidelines-for-transportation-vehicles-over-the-road-buses.

SECTION
3

Facilities

Overview

This section offers suggestions for advanced and improved facilities management practices. These suggestions may be helpful in meeting existing Federal reporting requirements as well as offering opportunities for reduced labor time and costs and more efficient and successful transit service delivery. Broadly, this section addresses three kinds of facilities:

- Maintenance Facilities
- Administrative Facilities
- Passenger and Parking Facilities

For passenger and maintenance facilities, transit agencies typically lead the design, operation, maintenance, renewal, and replacement activities. In the case of administrative facilities, agencies commonly lease space in private or local government buildings.

For facilities that will be overseen by the transit agency, an asset inventory is the foundation of the lifecycle management plan. Facility assets may be defined by the modal division or general operations category that has primary responsibility for management. Alternatively or additionally, assets may be classified by their location within the system, or by their individual owner or manager.

For the lifecycle management plan to be most useful, agencies should itemize each instance of a particular facility asset. For example, a transit agency with multiple roof structures on the same building should catalog the lifecycle management needs of each different roof structure rather than grouping them together into a single line item in the plan.

As an agency's asset management practices evolve and mature, it may be helpful to consider the framework or hierarchy depicted in Table 2-1.

In addition to the information provided in this section, FTA has published the *Facility Performance Measure Reporting Guidebook*, which focuses on data features regarding facility conditions and performance measures for administrative and maintenance facilities, as well as for passenger and parking facilities. It provides comprehensive procedures for developing facility performance measures to comply with FTA requirements related to facility condition assessment and reporting, and example photographs of relevant condition level ratings. This section complements the guidebook by discussing additional industry practices and considerations related to lifecycle planning for transit facilities.

Administrative and Maintenance 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, and operations and administrative space. All of these assets 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 such as 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 facility systems may have much shorter design lives.

Passenger and Parking Facilities

Passenger facilities are critical customer-facing assets, and good asset management practices for these facilities will help ensure customer safety and satisfaction. Passenger facility structures can include 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:

- 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.
- Unlike maintenance and service facilities, passenger facilities are often unmanned (or nearly unmanned) by transit agency staff and do not host agency workspace.

- Passenger facilities are located within the transit right-of-way and often on 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).

Table 3-1 provides a breakdown of asset types, elements, and sub-elements for each asset class. Although agencies are not required to report assets to NTD at the element/sub-element level, categorizing and inventorying assets down to this granular level may be useful in developing a robust asset management program. Agencies may also find it useful to develop an "Asset Subtypes" category, prior to identifying elements/sub-elements. These Subtypes may have different elements and subsequent maintenance and management activities. As Asset Subtypes are not required, they can be customizable for each agency and can be useful in developing your asset inventory.

Table 3-1

Facilities and Stations Asset Class Proposed Asset Hierarchy

<table>
<tr><th>1. Define Asset Class</th><th>2. Catalog Asset Types</th><th>3. Identify Asset Elements</th></tr>
<tr><td>Maintenance</td><td>• General purpose maintenance facility/depot
• Heavy maintenance & overhaul (backshop)
• Maintenance facility (service and inspection)
• Vehicle blow-down facility
• Vehicle fueling facility
• Vehicle testing facility
• Vehicle washing facility
• Other</td><td rowspan="4">• Substructure
• Shell
• Interiors
• Conveyance
• Plumbing
• HVAC
• Fire Protection
• Electrical
• Equipment
• Site</td></tr>
<tr><td>Administration</td><td>• Administration office / Sales office
• Combined administrative and maintenance Facility
• Revenue collection facility
• Other</td></tr>
<tr><td>Passenger</td><td>• At-grade fixed guideway station
• Bus transfer center
• Elevated fixed guideway station
• Exclusive grade-separated platform station
• Simple at-grade platform station
• Underground fixed guideway station
• Other</td></tr>
<tr><td>Parking</td><td>• Parking structure
• Surface parking lot
• Other</td></tr>
</table>

A further breakdown of Asset Sub-Elements can be found in the Condition Assessment guidebook.

This asset hierarchy is changed from that in the previous TAM Guide Supplement. An asset class for Administration has been added, encompassing facilities concerned with agency operation as opposed to direct service provision.

The previous classification of Service Facilities has been incorporated with the Maintenance asset class and Administration as it applies to administrative facilities. The revised Table 3-1 includes Parking as its own asset class, where it was previously included with Stations/Passenger Facilities.

Lifecycle Management Practices

This section offers suggestions for implementing new or different asset management practices for transit agency facilities. Whereas many facility management activities are comprehensive and successful, there are opportunities for improvement, as construction methods and site planning/design evolve alongside passenger expectations and in response to external pressures. For example, prevalence of extreme weather may lead agencies to improve and address building energy efficiency and resilience.

The building's substructure and shell often dictate the overall longevity and maintenance requirements. A building is commonly designed to last 25 years or more, at which point a recapitalization or at least substantial maintenance may be needed to extend the facility's useful life. All other building systems and subsystems, such as HVAC, plumbing, electrical, conveyances, and security, are contained within the building structure and, therefore, must be managed both in the context of their own performance and asset life (which is usually shorter than that of the structure), as well as their relationship to the overall structure and interaction with other subsystems. For example, HVAC systems rely on plumbing and electrical systems to function, and the maintenance approach for all three subsystems must coordinate with the others.

Differences in facility uses will also determine their maintenance needs. For example, maintenance facilities have high requirements for functional design and critical subsystems (power, electrical, etc.), as operations critical activities are occurring, but fewer requirements for frequent cleaning and daily maintenance. On the other hand, passenger facilities have high requirements for daily maintenance and care due to high traffic, exposure to weather, and the need to maintain a quality customer experience. Both typically have higher safety standards in comparison to administrative facilities due to potential risks and liabilities.

Although many agencies manage building maintenance through a single maintenance-management or work-order system, these systems do not often provide a comprehensive perspective on the performance of each of a facility's systems. Agencies commonly use specialized tools such as energy-efficiency or energy use management programs that address only HVAC and electrical system management. In managing a variety of facilities, transit agencies must assemble data and information from an array of sources and plans to provide a complete picture.

The following sections describe the lifecycle activities and considerations for three major classes of facilities and offer some organizational and management approaches specific to facilities asset management, including:

- Design and Procurement
- Operations and Maintenance
- Capital Rehabilitation and Replacement
- Condition Assessment and Performance Monitoring

Making Design and Procurement Decisions

New facilities are usually the product of a major system expansion or enhancement of the existing transit system. Maintenance facilities are typically built to last at least 50 years or a certain number of times beyond the life of the agency's normal revenue vehicle, but element systems may have much shorter lives. The facility design and procurement process affords an opportunity to consider new factors to improve lifecycle management. For example, 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. This section offers considerations for facility design and procurement decisions.

A Systems Approach

A systems engineering approach can help optimize facilities for operational needs by coordinating major functional agency workgroups, articulating a coherent transit system vision and objectively weighing needs, costs, and facility design criteria. A systems engineering approach drives improvement by precisely defining facility functional needs, mapping work processes within the facility, and conducting iterative design reviews.

Facilities are primarily work spaces for transit operations, maintenance, and administration, which define the agency's operational efficiency. Major facilities investments provide an opportunity for the transit agency's major functional divisions to collaborate to define operations needs over a long time horizon, and improve their approach to service delivery both within the agency and to customers.

At the facility level, the design should support the intended 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, 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).

Facility User Requirements

For all classes of facilities, but especially for passenger facilities, user requirements should be central to the design and procurement process. Basic qualitative and quantitative customer research, peer agency comparisons, and historical design and procurement review can result in a facility that better serves system and user needs.

Consulting and collaborating with all facility users, from maintenance staff and operators to station staff and riders, can dramatically improve final design. The design and procurement processes should specifically address safety, comfort, and access issues through the lens of maintainability and user experience. This includes projecting future needs related to technology, vehicle fuel (and having appropriate equipment and space to support), lifts and space to accommodate vehicles, and space to accommodate growth in the fleet.

Technology Specifications

When procuring technology such as building management systems, it is important to develop a set of functional requirements that do not rely on specific proprietary software and systems to reduce the likelihood that a transit agency will be confined to working with a single or specific vendor. Matching technology solutions to an agency's set of existing functional requirements is a better approach than evaluating—and possibly purchasing—vendor products on an *ad-hoc* basis.

Transit agencies should be aware of a technology's lifecycle. Systems early in the product lifecycle may have unproven specifications that can require change orders and modifications from what a transit agency might otherwise expect. On the other hand, more mature technology solutions can suffer loss of vendor support over time, and may suffer from parts shortages and interoperability issues as new systems come online.

Agencies may already have scoring systems in place, and decision support and comparative analysis techniques can provide a scaffolding for collecting and analyzing user requirements and specifications.

Automation, Standardization, and Simplification

Agencies can reduce costs by applying standardization and simplification across facility types and systems in several ways, including the following:

- Standardized equipment and elements 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 elements 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.

Transit agencies may find that incorporating "smart features" into the design of passenger facilities provides valuable data collection and remote monitoring capabilities. These technologies can help reduce the time required by agency staff to manage facilities and their elements. 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 and rapidly communicate with facility maintenance staff. Agencies may also use remote monitoring to identify issues related to temperature or HVAC, elevators and escalators, and lighting.

For example, agencies may deploy sensors that diagnose lighting problems and trigger backup lighting, both alerting maintenance staff to the issue and addressing a potential safety hazard. Although 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.

Quality Assurance and Control

Agencies can improve the design and procurement process by clearly defining and incorporating QA/QC to manage risks and ensure that all work is completed according to specifications using standard or best practices. Corrective action costs decrease when a defect is discovered early and increase as design and construction proceeds.

The construction phase is a critical risk period for any major facilities project. 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. Tracking systems should include issue identification, follow-up, and closure or resolution.

Performance Metrics and Specifications

Performance-based specifications can be used to outline detailed operational requirements of facilities. Such specifications should reflect a well-developed understanding of a facility's operational requirements, both existing and future.

Design teams may find significant value in reaching out to a variety of operations and maintenance staff to set facility performance standards, evaluate facility design, and identify potential issues. This approach can pre-empt the need for corrective measures, improve safety, and realize productivity savings.

Minimizing costs in the procurement stage (or in other stages of the asset lifecycle) can result in greater expense later in the lifecycle. For example, standards and ratings for high energy use systems such as HVAC offer more transparency about 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.

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).

Performance modeling can also help specify load requirements for critical equipment 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, systems such as public restroom plumbing, elevators and escalators, and ticket vending machines typically have high frequency maintenance needs because of frequent 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 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.

Risk Assessment and Mitigation

The facility design and procurement phase should include risk assessment and mitigation activities. If for any reason a vehicle maintenance facility was unavailable, it might be impossible to deliver transit service. 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.

For example, risk assessment can consider facility siting and the probability of flood risk, as weather and flood patterns have changed. Facility flooding is one of the most common causes of a transit maintenance facility shutdown. Design teams should consider advanced drainage systems and low-impact site design options for new passenger and maintenance facilities. Maintenance facilities should not need to resort to drainage pumps, which can be costly and unreliable.

Third-party activities on transit properties will have impacts on the lifecycle management of passenger facilities. Joint development projects and enterprise activities such as concessions and retail leases can provide income for transit agencies; these contracts should be carefully crafted to mitigate the transit agency's risk of burdensome facility maintenance, ensure access to all infrastructure, and allow for monitoring of the concessionaire's maintenance activities.

Another common risk that can be addressed during the design and procurement process involves right-of-way ownership. If a transit agency does not own the right-of-way where fixed-guideway service is operating, 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, a 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 coordination and should document these issues carefully.

Operations and Maintenance Considerations

Not every transit agency is responsible for its stations or other passenger facilities. Transit agencies with only bus and paratransit service often leave management of bus stops, shelters, and bus transfer stations to local governments that 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, maintenance, and replacement costs.

Maintenance Management Systems

Implementation of a maintenance management system will assist in planning and tracking maintenance requirements, leading to more informed decision making. Management systems can provide a centralized database of a facility's prior and planned maintenance, which allows agencies to proactively plan and create alternative solutions to mitigate any possible impacts from facility maintenance on transit service.

> By the nature of their exposure to physical elements, roofs are commonly the asset type of the facility shell for which special care must be paid to ensure safety and reliability. This includes both proactive processes to inspect and repair roofs as well as a shorter replacement lifecycle than other elements of the facility shell.

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.

Tracking Performance of the Facilities Management Plan

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.

Interdepartmental Coordination

Coordination between departments is critical for making well-informed decisions about facility maintenance. Since most facilities are shared by different operational departments, strategic communication and coordination about upcoming maintenance or changes in operation will reduce the possibility of duplication of maintenance, and potentially reduce costs by completing multiple tasks at one time.

Planned maintenance on a bus garage, for example, requires coordination between the maintenance and service departments, among others. Staff need to know which equipment may be impacted during the time of maintenance, and how this may impact dispatch and service provision. Advance planning and coordination between these departments can help minimize limit the impact of facility and vehicle maintenance on customers as well as unforeseen impacts on time and cost.

As part of a robust facilities maintenance program, asset managers should strive to not only replace critical elements as needed, but also to enhance them. For example, lighting systems in most transit facilities were originally constructed with fluorescent, always-on elements. As agencies become more conscious of energy cost efficiencies, considering a shift to sensor lighting and LED elements may concurrently reduce both asset lifecycle costs and energy bills.

Risk-based Approach to Facility Investment and Preventive Maintenance

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.

Performance-Based Contracting

A performance-based contract may be an effective strategy for monitoring facility maintenance costs and tracking 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. Contracts for cleaning, landscape maintenance, and graffiti removal are common in the transit industry and represent commodity services where high numbers of vendors can offer quality service and pricing.

Vertical conveyances (elevators and escalators) are typically one of the most complicated asset types contained in a transit passenger facility. Given their critical role in circulating riders to and from transit services and the complexity of the machinery leading to failure, they are frequently designed, operated, and maintained on a far more proactive schedule than other elements in the facility.

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.

Capital Rehabilitation and Replacement Considerations

Developing a Rehabilitation Plan

Rehabilitation is more extensive than general operation and maintenance and delays the need for partial or complete facility replacement, thereby extending the useful life. 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. Transit agencies should map this planned baseline into the facility's maintenance management system for comparison with ongoing condition assessments and actual maintenance activities.

Rehabilitation plans should follow processes similar to design and procurement, namely, taking a systems approach, comprehensive risk assessment and mitigation, and performance measurement. The plan may also include an assessment of whether rehabilitation work can be completed more efficiently in-house or through a vendor or the original manufacturer.

Decision Analysis

Decision analysis can be an important tool to support the timing of major rehabilitation and replacement projects. Major facilities projects typically grow out of long-range planning efforts, and transit agencies should maintain comprehensive and prioritized project lists for all facilities covering the short- to medium-term horizon. Agencies can use asset management planning software to model investment scenarios, including 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 able 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.

Delaying critical investments and operating facilities assets beyond their useful life can have serious consequences. Although the impact to an agency's financial bottom line may not be immediate, the change in risk profile is significant and should be tracked through condition reports and addressed in capital program prioritization. Although 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 Monitoring

Performance modeling can help maximize the value of facility renovation and rehabilitation projects. There is often significant latitude for redesign or a new approach when facilities are renovated or replaced. Unlike a vehicle that requires a specific element with exact specifications, a building often can 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, costs, and customer behavior to evaluate upgrade and replacement options.

Thus, 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.

Performance modeling for passenger facilities should reflect goals specific to passenger-facing assets. For instance, passenger facilities should emphasize safety and cleanliness. Passenger input from customer satisfaction surveys and a transit agency's customer service line are important performance metrics. 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. Transit agencies can leverage NTD reporting requirements to accomplish performance monitoring procedures. Tables 3-2 and 3-3 outline 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 3-2

Maintenance and Administrative Facilities Performance Metrics

Asset Class	Performance Target Reporting Requirement Element Categories	Sub-Element Considerations*
Maintenance and Administrative Facilities	• Substructure • Shell • Interiors • Conveyance • Plumbing • HVAC • Fire Protection • Electrical • Equipment • Site	• Concrete strength** • Crack monitoring** • Foundation • Superstructure/structural frame, including columns, pillars, and walls • Windows and doors • Stairs and landings (exterior and interior) • Elevators • Escalators • Water distribution • Sanitary waste • Heating/cooling generation and distribution systems • Chimneys and vents • Standpipes • Electrical service and distribution • Communications and security** • Landscaping and irrigation • Site utilities

**This list of sub-element considerations required by NTD is not exhaustive.*
***These sub-element considerations are not required as part of NTD reporting but should be considered as part of a robust condition assessment.*

Table 3-3

Passenger Facilities' Performance Metrics

Asset Class	Performance Target Reporting Requirement Element Categories	Sub-Element Considerations*
Passenger Facilities	• 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 shelter, as well as parking spaces in lots • Customer satisfaction • Cleanliness of stations and shelters • Noise level • Overcrowding	• 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

**This list of sub-element considerations required by NTD is not exhaustive.*
***These sub-element considerations are not required as part of NTD reporting but should be considered as part of a robust condition assessment.*

Condition Assessment and Performance Monitoring

Given that a transit agency's facility 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 process. The program should cover all facility assets and map to the asset inventory. Condition assessment and performance monitoring should:

- 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.

Timing for Maintenance and Rehabilitation Projects

An optimal capital maintenance and rehabilitation program for facilities focuses on timing projects based on observed asset condition. Whereas 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 should not only ensure the performance monitoring program comprehensively covers all facility assets to a reasonable level of detail but 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.

Facility performance monitoring data may be collected from building management systems, condition inspections, facility maintenance records, security personnel, and workspace users in other departments. Effective business processes ensure these data are accurately recorded in a single database accessible throughout the organization.

Inspection Protocols and Principles

Inspections are often the most cost-effective method to assess the condition of and identify issues related to facility structures. Facilities managers should have precise procedures for both higher-frequency routine inspections and more-detailed structural inspections. The procedures should be kept up-to-date as practices 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. This allows for inspection histories to be available digitally and easy comparison of asset condition over time. Third-party facility audits can provide quality control of an agency's practices and greater expertise for non-routine inspections (such as an HVAC air balance test). Independent building condition assessments can help score and prioritize projects for capital planning.

Maintenance staff can perform many inspections as part of routine preventive maintenance activities (for example, monitoring for structural cracks or drainage issues). Methods include using thermal scanning to reveal water-logged insulation, openings in the exterior envelope of buildings, and broken seals in insulated glass, during preventative maintenance. Such scanning allows an agency to identify issues before they become serious and to address them proactively.

FTA TERM Scale

Transit agencies must assess facility condition and report some elements to the NTD. For standardization, agencies should refer to the FTA methodology[17] on

[17] https://www.transit.dot.gov/regulations-and-guidance/asset-management/tam-facility-performance-measure-reporting-guidebook.

calculating performance measure ratings using the FTA TERM scale. Ratings of individual assets should be aggregated to monitor the overall condition of the facility. Although only a limited number of elements are reported to NTD, it is useful for transit agencies to conduct a broader assessment of facility elements, in order to better understand and manage facility condition. The TERM rating scale is outlined in Table 2-3.

Industry Standards

The following list outlines any industry standards associated with the lifecycle of the facility and station 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.
  - *ADA Standards for Transportation Facilities* – contains technical requirements for accessibility to sites, facilities, buildings, and elements by individuals

[18] This supplement defines industry standards as requirements, standards, or guidelines that exist currently or are pending.

[19] Available for purchase at https://www.iso.org/standard/68021.html.

[20] https://codes.iccsafe.org/public/document/IBC2018. Available for purchase at https://www.asce.org/templates/publications-book-detail.aspx?id=24136.

[21] Available for purchase at https://www.concrete.org/store/productdetail.aspx?ItemID=31814. Available for purchase at https://pubs.aws.org/all-publications/492. https://www.aisc.org/publications/steel-standards/.

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 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:
  - 13, Standard for Installation of Sprinkler Systems[26]

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[22] Americans With Disabilities Act: https://www.access-board.gov/guidelines-and-standards/transportation/facilities/ada-standards-for-transportation-facilities.

[23] https://www.ashrae.org/technical-resources/standards-and-guidelines.

[24] Available for purchase at https://www.techstreet.com/boma/standards/unified-approach-for-measuring-office-space-for-use-in-facility-and-property-management?product_id=2034558.

[25] https://catalog.nfpa.org/Complete-List-of-Codes-and-Standards-C182.aspx.

[26] https://catalog.nfpa.org/NFPA-13-Standard-for-the-Installation-of-Sprinkler-Systems-C196.aspx.

- 25, Standard for Inspection, Testing, and Maintenance of Water-based Fire Protection System[27]
- 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages[28]
- 90A, Standard for the Installation of Air-Conditioning and Ventilating Systems[29]
- 90B , Standard for the Installation of Warm Air Heating and Air-Conditioning Systems[30]
- 130, Standard for Fixed Guideway Transit and Passenger Rail System[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) Illustrated Plumbing Codes Design Handbook* – provides guidance on applying International Plumbing Code and Uniform Plumbing Code in design.[33]

- Stations
  – APTA guidelines of technical provisions for the design and construction of heavy duty elevators, escalators, and moving walkways:
    - Heavy Duty Transportation System Elevator Design Guidelines[34]
    - Heavy-Duty Transportation System Escalator Design Guidelines[35]
    - Heavy Duty, Transportation System Moving Walk Design Guidelines[36]

[27] https://catalog.nfpa.org/NFPA-25-Standard-for-the-Inspection-Testing-and-Maintenance-of-Water-Based-Fire-Protection-Systems-C243.aspx.

[28] https://catalog.nfpa.org/NFPA-30A-Code-for-Motor-Fuel-Dispensing-Facilities-and-Repair-Garages-C245.aspx.

[29] https://catalog.nfpa.org/NFPA-90A-Standard-for-the-Installation-of-Air-Conditioning-and-Ventilating-Systems-C298.aspx.

[30] https://catalog.nfpa.org/NFPA-90B-Standard-for-the-Installation-of-Warm-Air-Heating-and-Air-Conditioning-Systems-P1216.aspx.

[31] https://catalog.nfpa.org/NFPA-130-Standard-for-Fixed-Guideway-Transit-and-Passenger-Rail-Systems-P1229.aspx.

[32] https://www.smacna.org/technical/papers-and-guidelines/technical-paper/2014/06/24/architectural-sheet-metal-manual.

[33] Available for purchase at https://www.aspe.org/content/illustrated-plumbing-codes-design-handbook-electronic-download.

[34] https://www.apta.com/wp-content/uploads/Standards_Documents/APTA-RT-EE-RP-002-03.pdf.

[35] https://www.apta.com/wp-content/uploads/APTA-RT-EE-RP-001-02_Rev_3.pdf.

[36] https://www.apta.com/wp-content/uploads/Standards_Documents/APTA-RT-EE-RP-005-04.pdf.

- National NFPA 88A Standard for Parking Structures – standard covers construction, protection, and hazard controls in open and enclosed parking structures.[37]
- *National Parking Association Parking Facility Maintenance Manual* – covers standard maintenance practices for parking structures.[38]
- *National Parking Association Guidelines for Parking Geometrics* – covers the design and construction of parking facilities including parking structures.[39]
- *Washington State Department of Transportation Ferry Terminal Design Manual* – provides guidelines for the design of terminals to optimize capital and operating investments.[40]

[37] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=88A.

[38] Available for purchase at https://weareparking.org/store/ViewProduct.aspx?id=5376933.

[39] Available for purchase at https://weareparking.org/store/ViewProduct.aspx?id=7935888.

[40] https://www.wsdot.wa.gov/publications/manuals/fulltext/M3082/TDM.pdf.

SECTION 4

Equipment

Overview

The Equipment Asset Category covers two unique asset classes, Service Vehicles (Non-Revenue) and Equipment assets. These two classes represent an array of different asset types. In particular, Equipment consists of assets used in service delivery, such as fare equipment or passenger amenities, and assets used in maintenance or administrative facilities, such as vehicle lifts or office equipment.

Equipment assets should be carefully defined to clarify management and reporting, as these assets may sometimes be considered as an element of a more complex asset, such as a facility, revenue vehicle, or other asset class depending on your asset hierarchy. Based on definitions established by FTA, Equipment classes are categorized as:

- **Service Vehicles (Non-Revenue)** – any rubber-tire or steel-wheel vehicle that is not used for the provision of revenue service, including:
  - Automobiles and light-duty trucks, such as sport utility vehicles (SUVs), vans, and pick-up trucks, usually used for non-revenue activities, such as maintenance visits and fleet management.
  - Heavy-duty trucks, such as tow trucks used for towing buses, forklifts, and heavy service trucks, including service trucks with hi-rail equipment, normally used for fleet maintenance, asset recovery, work crew in-field service vehicles, and inventory management activities.
  - Any heavy-duty vehicle, including specialized track equipment used for maintenance, construction, or repairs of track assets, as well as specific types of heavy equipment for construction or maintenance purposes.
- **Equipment** – in general, any asset that is semi-permanent in nature, has a useful life over one year, and does not comprise the core functionality of a larger asset (such as a Facility, Vehicle, or Infrastructure asset), including:
  - Customer equipment on vehicles and at passenger facilities, such as fare equipment, shelters and benches, signage and passenger amenities, or landscaping and public art, provided in the delivery of services.
  - Service equipment on vehicles or infrastructure, in facilities, or used remotely, such as maintenance and shop equipment, office and IT equipment, communications and signal equipment, or security and surveillance equipment, used by personnel in their day-to-day work activities.

Equipment considered to be a permanent part of a larger asset is typically categorized as an element of the larger asset rather than as a distinct piece of Equipment. There is some discretion on the part of the agency to define equipment as Equipment or asset elements appropriately. The sections below provide additional guidance on this topic.

Service Vehicles (Non-Revenue) and Equipment with value over $50,000 must be included in the agency's TAM plan. Only Service Vehicles (Non-Revenue) need to be submitted to NTD for asset reporting.

Table 4-1 provides a breakdown of asset types and elements for each asset class. Although agencies are not required to report assets to NTD at the element level, categorizing and inventorying assets down to this granular level may be useful in developing a robust asset management program. Agencies may also find it useful to develop an "Asset Subtypes" category prior to identifying elements/sub-elements. These Subtypes may have different elements and subsequent maintenance and management activities. Since Asset Subtypes are not required, they can be customize to each agency, and can be useful in developing your asset inventory.

Table 4-1

Equipment Asset Category Hierarchy

1. Define Asset Class	2. Catalog Asset Types	3. Asset Elements
Service Vehicles (Non-Revenue)*	• Automobile (AO)* • Trucks and Other Rubber-Tire Vehicles* • Steel Wheel Vehicles*	• Wheel and axle sets • Power plants and propulsion systems • Braking systems • HVAC systems • Auxiliary power systems • Transmissions/gearboxes
Equipment**	• Fare Equipment • Maintenance Equipment • Facility Equipment • IT Equipment • Office Equipment • Communication Equipment • Security/Surveillance Equipment • Signal Equipment • Bus Shelter • Signage • Passenger Amenities • Landscaping/Public Art • Electrification/Power Distribution • Miscellaneous	Customize for agency specific classification (if required)

For each type of asset held by an agency, there may be various service vehicles in operation that will differ based on agency size, geographic region, and modes of service. Likewise, the Equipment class covers a broad range and different forms of equipment. Based on agency maintenance approaches and service profile, developing a customized subtype classification scheme can help plan for the specific maintenance and management activities that different forms of Equipment require.

Lifecycle Management Practices

This section identifies approaches asset managers may take in thinking about the management, tracking, and lifecycle of non-revenue service vehicles and Equipment. In the case of non-revenue vehicles, transit agencies are less likely to employ mature asset management practices as they might for revenue vehicles. Non-revenue vehicles often operate until they fail (unless maintenance is outsourced) and maintenance outside of standard preventative measures (fluid and filter changes, tire rotations, etc.) is frequently unplanned (i.e., reactive or unscheduled).

Non-revenue vehicles include common cars, SUVs, and light-duty trucks that can easily be leased. Alternatively, transit agencies may own specialized vehicles with customized equipment that requires special expertise to maintain. In the first case, vehicle leases reduce the need for maintenance planning because maintenance activities are typically part of the lease contract. In the latter case, transit agencies may face challenges in allocating resources to properly maintain such vehicles.

Whereas some equipment is operated until failure, there are some notable exceptions to this approach depending on the criticality of the equipment. These include electrification and power distribution equipment, which must perform consistently in order to ensure continuous operation of any mode requiring traction power as a source of propulsion. Another example includes certain types of specialized communications equipment, which may require more robust and higher frequency maintenance activities to ensure dependability of operations.

Although most equipment assets see little to no maintenance beyond what is considered minimally routine or conducted as necessary, fleet and maintenance management systems can assist with identifying which assets may require maintenance on a regular basis. These new systems include features such as remote sensors and "smart" technology that utilize integrated systems and predictive analytics to assist asset managers in identifying when maintenance activities should occur to both improve reliability and reduce investment in new capital assets.

An agency with the processes in place to effectively integrate and analyze this growing repository of real-time maintenance data can better identify opportunities for efficiency and cost savings, and better manage assets that may otherwise be overlooked as part of an improved asset management approach.

Making Design and Procurement Decisions

Identification of Needs

When considering whether to procure new service vehicles or equipment, an agency will take different approaches based on the asset class and type but in both cases should start with an existing and long-term identification of needs.

Service Vehicles (Non-Revenue)

For non-revenue service vehicles, the agency may consider the current and future number of employees who will use service vehicles and the functional roles assigned to those employees. Employee roles that typically require the use of a service vehicle include operations support staff (non-mechanical), mechanical staff, and staff conducting specialized maintenance work.

> Agencies should always consider the characteristics of the revenue service the vehicles will support, including number of revenue service hours and miles, overall revenue fleet size, types of linear and fixed facility assets, and geographic span of the service area.

Operations support staff who need an agency-provided service vehicle usually require some type of automobile, pickup truck, van or SUV. Determination of the number and type of each vehicle should be based on overall staff levels, size of network, hours of operation, and whether or not any personnel are identified as essential.

Transit agencies that are part of a larger unit of government (e.g., a City or County) frequently consider light-duty service vehicle requirements in partnership with the top-level jurisdiction, since these vehicles can be shared across multiple transit and non-transit needs. Agencies may be able to take advantage of discounts through bulk purchasing for these vehicles.

Mechanical and maintenance staff usually require some type of light-duty, heavy-duty or specialized vehicle depending on the type of work being performed. Such vehicles may include service vehicles for field repairs, heavy-duty tow trucks for buses, or specialized track vehicles, to include plows, re-railing vehicles, or inspection cars. In all cases, types of service, service level, service hours, and number of personnel needed to perform required maintenance, and inspections must be considered when identifying types of vehicles and quantity.

Some agencies may find that outsourcing this type of work and the associated service vehicles may be a cost-effective alternative. Whether or not outsourcing will be beneficial should be weighed against system reliability, maintenance needs, and associated costs.

Equipment

For equipment, identification of needs can vary greatly based on the type of equipment required and functions for which it will be used. Typical factors to consider for common equipment types are:

- **Fare Equipment** – number of vehicles and passenger facilities, facility design (e.g., number of entrances and passenger flow configurations), fare payment methods (e.g., purchase agents, vending machines, mobile devices), fare validation methods (e.g., validators, visual inspection, on/off-board, fare gates)
- **Passenger Features** – number of stops, stations, or passenger facilities; strategy and budget for overall customer experience
- **Linear Infrastructure Equipment (Traction Power, Signaling)** – linear miles and track miles of right-of-way; vehicle power and communications requirements; track configuration (e.g., curves, junctions, wyes); current maintenance backlog, frequency of maintenance for each element/ sub-element; geographic-based weather considerations.
- **Mobile Communications Equipment** – functional role of personnel, number of personnel in each position; communication requirements, spare ratio to account for unit replacement; charging time, charging station locations; operational safety aspects (restrictions against drivers and hand-held radio/phone use).
- **Maintenance Equipment** – number and size of maintenance facilities, quantity and types of revenue vehicles and infrastructure, type of work being performed by maintenance and mechanical staff
- **IT Equipment and Office Equipment** – number of facilities; quantity, area, and type of workspaces; number of employed personnel requiring a work station

Procurement

Since most service vehicles and many equipment assets are replaced at the end of their useful lives, with minimal to no maintenance conducted throughout the asset's life, focusing on up-front cost savings balanced against the expected asset lifecycle and reliability is typically an acceptable and cost-effective approach for procurement. As the asset grows more complex or is anticipated to use replaceable elements or consumables, greater emphasis on asset quality and lifecycle cost considerations may prevail over initial capital cost factors.

Frequently, the most economical procurement mechanism for service vehicles will be jurisdiction-wide, as county- and statewide fleets are larger than agency-wide fleets. Depending on quantity, agencies that need to purchase only a small number of vehicles may find the most cost-effective approach to procurement is direct purchase through a commercial dealer for both operational (non-mechanical) and specialized equipment.

Approaches to procurement of equipment will differ greatly based on the type of equipment. For example, fare boxes are usually procured or replaced when a new or updated fare payment system is procured. Other items such as shop equipment may be purchased as needed, whereas a bus lift may only need to be purchased upon failure. Bulk purchasing and ongoing asset replacement plans are often the most effective strategies for procurement of low-cost/high-quantity assets, such as office furniture and desktop IT hardware/software, and some passenger amenities.

Long-Term Planning

The service vehicle and capital procurement process, which can be relatively straightforward, should be conducted in a manner that is as efficient and simplified as possible, which typically means assessing and leveraging economies of scale. Alternatively, procurements that occur outside of comprehensive long-term analyses can have detrimental impacts on an agency's operations. While the procurement process may be simplified, it should still be programmed.

Some equipment items costing less than $50,000 may be considered a "stand-alone asset" rather than a "primary asset," and the quantity and frequency of purchases should be planned for on an ongoing basis. Service vehicle purchase and replacement should be included in long-term capital investment plans, while some minimum of annual equipment costs should be assumed on an ongoing basis. These annual equipment costs should be adjusted for years in which larger and more expensive assets are expected to be replaced.

Contracting and Evaluation Methods

The following contracting and evaluation methods can be used for different asset types:

- **Direct Purchase** – for service vehicles, direct purchase of assets through a competitive procurement or blanket contract should almost always be used if the overall cost and quantity of the vehicles is significant. The main method of evaluation should be based on price, ability to deliver on time, and ability to deliver quality and reliability as specified. Specialized service vehicles may be purchased according to the same approach, but in some instances where the type of service vehicle is highly specialized, sole-sourcing may be needed based on integration with existing equipment.

  Equipment contracting decisions should focus on product quality, ease of systems integration, and overall cost. In some cases, interoperability of specialized hardware and software may be a paramount concern.

- **Leasing** – leasing assets, especially service vehicles, can represent a significant cost savings over direct purchase. If leasing costs are less than the costs associated with the direct purchase and maintenance of an asset, and factoring in depreciation with any resale, it may be a preferred approach. If the service vehicles are not highly specialized and do not require any or more than minimal customization, leasing may be the most cost-effective contracting method.

  The same approach can be used when analyzing a leasing option for equipment, if leasing is available for the equipment type being procured. The likelihood of leasing options being available is usually dependent on how ubiquitous the asset type is across multiple industries.

- **Performance contracts** – such contracts fix the transit agency's 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. One example of this kind of financially-based risk management approach is leasing tires, whereby agencies pay the tire vendor for a tire supply by the mile rather than purchasing tires directly.

Operations and Maintenance Considerations

With both classes of equipment (Service Vehicles and Equipment), agencies should determine the level of maintenance for each type of asset at the outset of the planning period and develop maintenance plans that are reviewed at periodic intervals. The data elements selected to assist with decision-making should be based on agency-wide service delivery goals and should align with the agency's maintenance strategy for the specific type of asset. Examples of maintenance strategies include:

- Run-to-Failure
- Preventive Maintenance
- Predictive Maintenance
- Reliability Centered Maintenance

A later section provides more detail about what each of these maintenance strategies entails.

Service Vehicles (Non-Revenue)

General service vehicles for support and operational staff will always require some maintenance, usually according to manufacturer requirements, for such events as oil changes, tire rotation, and inspections. Depending on the contractual approach and how long the agency owns the asset, maintenance work can increase and a cost-benefit analysis for the service vehicle fleet must be conducted to determine if the costs of additional maintenance work over time is more effective than replacement.

The same approach can be taken with heavy-duty trucks. More specialized equipment should be handled on a case-by-case basis depending on the criticality of the equipment in meeting agency or customer needs and the relative scarcity of the asset itself. Operators should strive to follow manufacturer's specifications for preventative maintenance and corrective repairs.

Equipment

The maintenance approach for equipment will be unique to the specific asset type. Fare equipment typically requires significant maintenance that needs detailed planning to balance parts availability, spare ratios, and specialized skills. Likewise, traction power, communications, and signaling equipment (and all associated elements and sub-elements) should be maintained on a frequent schedule given their complexity and criticality.

Many types of maintenance equipment, such as general shop tools, office equipment, and some general use communication equipment and hardware, require little to no maintenance and are expected to be replaced upon failure. With assets that are expected to be replaced upon failure, every agency should establish a methodology for the best approach to replace assets. Agencies may consider the following strategies:

- Establish a spare ratio for large cost assets, elements and sub-elements of critical capital items, especially those which require a long-lead time for purchase fulfillment.
- Monitor inventory turnover and lead times to ensure elements and sub-elements are available when needed, but also monitoring and controlling for carrying costs.
- Some assets should be procured through a staggered approach, to ensure asset replacement costs are consistent from year-to-year, reducing the possibility of shortages or large spikes in replacement costs

Asset management, maintenance management, and capital planning systems that collect these data can help asset managers and maintenance staff develop or refine maintenance and replacement policies. These systems can assist with analysis of different scenarios and options, but the key to any successful approach is data quality and frequency of data collection.

Essential vs. Ancillary

Although the assets in other categories (Revenue Vehicles, Facilities, and Infrastructure) can almost exclusively be called essential, many of the assets captured under the Equipment category may be considered useful but not essential to the successful operation of an agency's system. Identifying which assets are ancillary as opposed to essential can help agencies understand maintenance or replacement priority based on available staff, funds, and overall service priorities.

Examples of ancillary assets include landscaping and public art, some office equipment and service vehicles, and even bus shelters and passenger amenities. Although these assets may improve operations or the overall passenger experience, agencies balancing competing pressures for operating and maintenance dollars will frequently de-prioritize ancillary assets over those essential to safe and reliable day-to-day operations. These strategies will vary by agency, geography, and other factors. For example, operators in extreme climates may find that bus shelters and other passenger amenities are essential to protecting passengers from the elements and ensuring their safety. An agency may deem it essential to have one piece of maintenance equipment available at all times, such as a bus lift, but optional to maintain additional lifts; although the additional lifts can reduce maintenance wait times, they are not essential to keeping revenue service operating.

Essential assets usually include:

- Service vehicles and specialized equipment to perform maintenance and safety inspections
- Fare vending machines to collect passenger fares
- Hardware and software signaling and communications equipment
- Maintenance management software
- Field tablets for inspector use

Increased Efficiency

Many equipment items can assist staff in completing existing processes in a more efficient and effective manner. When analyzing the need for different equipment types, agencies should consider opportunities to improve service outcomes by adjusting current processes or using available tools to improve the efficiency of staff or operations. Examples include:

- Deploying a single asset, maintenance, inspection, and inventory management system
- Integrating existing systems with a separate decision support tool to support key decision processes, thereby reducing implementation time and difficulties
- Providing maintenance and inspection staff with tablets to ensure all staff involved in similar activities are looking at the most up-to-date information
- Removing bus-based fare boxes and moving to a proof-of-payment approach to fare validation, thereby greatly reducing fare box maintenance costs and improving bus dwell time
- Procuring and deploying new AVL systems and public information displays to improve the customer experience, and reduce both complaints and overcrowding

- Outsourcing the construction and maintenance of bus shelters to advertising agencies to reduce overall staff maintenance demands

Optimization strategies and total cost analyses should be conducted on an ongoing basis to avoid de-prioritizing asset maintenance or replacement to save in one area (asset costs) while inadvertently increasing labor costs and total costs or diminishing service quality, reliability and safety.

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. Although most ticket vending machines and fare gates 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.

Fare collection equipment availability and reliability are critical metrics to track; their performance directly determines a transit agency's revenue. 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. Electronic fare collection failures frequently are caused by software rather than hardware issues, and these issues should be closely tracked with a prioritization process in place to address issues. 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. 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 4-2 provides examples of diverse metrics for monitoring fare collection system performance.

Table 4-2
Fare Collection 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

Capital Rehabilitation and Replacement Considerations

Replacement Policies and Capital Planning Tool

Some equipment assets (e.g., fare equipment, traction power, communications, and signaling equipment) require significant levels of maintenance. For these assets, agencies should consider a systems approach to their maintenance, including all associated elements and sub-elements. For most equipment assets that require minimal to no maintenance and are replaced upon failure or upon reaching the asset's estimated service life, developing a multi-faceted approach may not be the most efficient method for managing these assets.

For those assets that do not require routine or significant maintenance, agencies can develop asset replacement standards for each asset type or subtype, depending on the size and complexity of service delivery, and operational requirements. These standards should be included in an asset management policy focusing on data elements that can be easily tracked to determine the asset replacement schedule. Such data elements may include asset age, mileage, hours of service, or condition assessment. In some cases, the asset can simply be flagged as an asset type that is to be replaced upon failure, without any data element to track.

A capital planning tool, whether it is a sophisticated web-based system or a simple database or spreadsheet tool, can help track when assets are due for replacement. Using a capital planning tool can assist an agency with tracking the expected annual costs associated with equipment replacement over a longer time period. Combining a capital planning tool with an equipment replacement policy can help agencies better address annual and ongoing expected equipment replacement costs.

Prioritization and Optimization

As agencies identify potential annual equipment replacement costs and the types of equipment expected to be replaced, it is particularly important to prioritize and optimize use of limited resources. This includes identifying which assets are highest priority and must be replaced within the coming fiscal or calendar year and assets that should be replaced but are not considered essential or as high priority and replacement can be delayed. Examples of data elements that can be used to prioritize asset replacement include:

- Available capital funding
- Transportation Economic Requirements Model (TERM) Rating
- Age to Useful Life Ratios
- Condition or performance metrics
- Usage metrics

Optimization takes prioritization a step further by focusing not only on agency priorities, but also on identifying the most efficient and effective replacement strategy over a multi-year timeframe. Optimization usually includes additional data sets associated with assets, funding, or any number of empirical data sets that are supposed to complement policy-based priorities. Examples of variables and constraints that can be used to optimize replacement policies over a long-term horizon include:

- Failure rate
- Criticality and risk scores
- Cost of replacement and/or cost of deferred maintenance
- Service impact
- Service delivery goals
- Anticipated long-term capital costs as compared to anticipated budget

As agencies analyze state of good repair (SGR) priorities of each asset category and balance those priorities against available resources and service delivery metrics, focusing on optimization-based prioritization of asset replacement is an efficient approach to maintaining an effective capital investment plan. The complexity of both decision making processes and the tool used to conduct such an approach should be weighed against the complexity of agency investment decisions, and available budget.

Condition Assessment and Performance Monitoring

Agencies can use a standardized or customized method to assess condition and monitor performance of assets. One standardized approach is TERM, which is based on a 1 to 5 scale. The TERM rating scale is shown in Table 2-3.

Performance monitoring can also be achieved by identifying KPIs according to individual agency investment and service priorities. Any number or type of KPIs can be used as long as the indicators are specific, measurable, attainable, relevant, and time-bound.

Equipment Categorization and Classification

As described above, some equipment can be considered primary or "stand-alone" assets within the Equipment category, especially above $50,000. In many cases, however, an equipment item is more appropriately treated as an element or sub-element of a larger, more complex primary asset. Element and sub-element equipment should be assessed separately and aggregated to obtain an overall condition or performance rating for the primary asset.

Primary Assets

As all service vehicles are a primary or stand-alone asset, agencies should perform condition assessment of these vehicles in a manner similar to that of revenue vehicles, although the service vehicles with shorter service lives may require substantially less detail as part of a condition assessment. Equipment that is semi-permanent in nature, has a useful life over one year, and does not comprise the core functionality of a larger asset (such as a Facility, Vehicle, or Infrastructure asset), could be treated as a primary asset. These could be assessed systematically based on an overall assessment plan for the asset subtype.

Element and Sub-Element Assets

When an item is included as a permanent or integral part of a larger asset, then it may be appropriate to assess the condition as part of the assessment of the larger asset. Equipment assets can be included as part of a Facility, Vehicle (Revenue or Non-Revenue), or Infrastructure (Linear) asset. Agencies can modify and customize the following approach to assessing the condition and primary/element status of Equipment assets:

- **Facility** – if an item of equipment is not a permanent part of a facility (an add-on item that may be removed or replaced) and is not an integral item of equipment for the long-term continued use of the facility, then it should be categorized under Equipment (i.e., signage, bike racks, or furniture). If the equipment is a structural part of a facility or integral to the proper functioning of a facility, then it should be categorized as either an Element or Sub-Element of a facility (i.e., HVAC, hydrants, and other fire protection specialties, and elevators).

  This distinction can be difficult to determine, for example, with equipment items such as fare gates or turnstiles within a passenger station. Although the structure may be semi-permanently installed and considered part of the facility, the electronics may be considered Equipment. In such cases, it is important for the transit agency to set its own policy and standardization regarding categorization of assets, to include whether or not to consider purchase cost of the asset as part of the analysis.

- **Vehicle (Revenue or Non-Revenue)** – if an item of equipment is not a permanent part of a vehicle (an add-on item that may be removed or replaced), is more than $5,000 in value (or a figure determined by the agency), and does not constitute a core functionality within a bus (as determined by the agency), then it should be categorized under Equipment and assessed separately (e.g., bike racks or snow plows).

  If an Equipment asset on a vehicle is easily removed, is less than $5,000 in value (or a figure determined by the agency), will likely be installed on the vehicle for the entirety of the vehicle's service life, and the vehicle cannot effectively operate without the equipment, then it should be assessed as part of the vehicle rather than a separate Equipment asset (e.g., destination signs).

- **Infrastructure (Linear)** – it is generally recommended that all equipment used for infrastructure assets be categorized as part of the corresponding linear asset record data structure to facilitate identification of assets within a designated segment.

  In some cases, if equipment is being used along a right-of-way and is identified according to a geo-reference point or a latitude/longitude or is maintained and controlled outside of the right-of-way, then the equipment should be categorized as Equipment. Specific examples include items such as some wayside equipment, some software and communications equipment, signal-related hardware, and traction power equipment such as transformers and substation related equipment.

Agencies should establish standard policies for whether to track and monitor certain types of Equipment separately as primary assets or as an element/sub-element within a primary asset.

Collecting and Maintaining Data

It is particularly important to ensure that equipment asset data are categorized and stored in a hierarchy that meets agency needs while facilitating internal and external (including NTD) reporting. Following the hierarchy outlined in Table 4-1, an agency will collect the data required by NTD and make it simple to complete reporting. Following this hierarchy also means the agency will collect more information than what is required by NTD and provide some of the information needed to enhance an asset management program. Agencies should establish a policy and approach for maintaining a current equipment inventory. Service vehicles can be handled in a similar method to revenue vehicles, whereas equipment will likely require a higher frequency of data updates. Data update frequency differs based on data element and equipment type, but agencies should establish a minimum frequency for adding new equipment and removing old equipment to ensure that the inventory list is up-to-date.

New asset inventories should be added to any inventory tracking system upon delivery or final inspection and acceptance. Asset disposition should be conducted on an as-needed basis and may include tracking multiple aspects of the disposition process such as removal from active service, sale of the assets, or scrapping the asset.

As more agencies update existing asset inventory databases to better capture asset data and classification hierarchy or procure new asset management systems, it is important to carefully consider the best approach for the agency. Some agencies may decide to procure an enterprise asset management (EAM) system, which may be beneficial to very large agencies with the available budget and dedicated staff and expertise with implementing and training staff on a complex system.

Other agencies may decide to take a different approach, such as procuring new (or maintaining existing) smaller systems that include one or more modules within an EAM or finding a data or decision-making system that can serve as an "over-the-top" layer to pull relevant data from multiple systems into a single location.

This multi-system approach can be very cost-effective and relatively easy to implement because it does not require replacing existing systems and can combine multiple data sources using modular-based tools to transfer data, such as Application Programming Interfaces (API), JSON exports, or CSV files sent through an FTP site. Additional approaches include identifying existing systems in use at the agency, regional, or state levels, which may be used or expanded upon at little to no cost by sharing investment burdens across agencies.[41]

Industry Standards

In addition to the suggestions offered in this supplement, several transit and transportation industry groups have created standards for Equipment management; service vehicles (non-revenue) management approaches should utilized the references within the Revenue Vehicles section.

Service Vehicles (Non-Revenue)

- Federal Motor Carrier Safety Administration Regulations[42]
- Inspection, Repair, and Maintenance Regulations – systematic inspection of vehicles to ensure that vehicle parts are in working order at all times.[43]

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[41] This supplement defines industry standards as requirements, standards, or guidelines that exist currently or are pending.

[42] https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&ty=HTML&h=L&mc=true&=PART&n=pt49.5.390.

[43] https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&ty=HTML&h=L&mc=true&=PART&n=pt49.5.396.

- *AAR Manual of Standards and Recommended Practices* – includes standards for the design, fabrication, and construction of freight cars, maintenance and rehabilitation, and management practices.[44]
- *AREMA 2018 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.[45]
- *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.[46]

Equipment

- *APTA Published Standards: Technology for Transit Systems Standards Program.*[47]
- *APTA Published Standards: State of Good Repair.*[48]
- *APTA Published Standards: Security for Transit Systems Standards Program.*[49]
- *APTA Published Standards: Procurement.*[50]
- FRA Office of Railroad Safety – 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.[51]
- Parts and Accessories Necessary for Safe Operation Regulations – establishes safety standards for elements such as lighting, electrical wiring, brake systems, windows, tires, and others.[52]
- 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.[53]

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[44] Available for purchase at https://www.aar.com/standards/publications.html.

[45] Available for purchase at http://www.arema.org/AREMA_MBRR/AREMA_MBRR/AREMAStore/MRE.aspx.

[46] https://www.access-board.gov/guidelines-and-standards/transportation/vehicles/ada-accessibility-guidelines-for-transportation-vehicles-over-the-road-buses.

[47] https://www.apta.com/research-technical-resources/standards/technology/.

[48] https://www.apta.com/wp-content/uploads/Resources/gap/fedreg/Documents/Defining.a.transit.asset.management.framework.to.achieve.a.state.of.good.repair.pdf.

[49] https://www.apta.com/research-technical-resources/standards/security/.

[50] https://www.apta.com/research-technical-resources/standards/procurement/.

[51] https://www.fra.dot.gov/Page/P0010.

[52] https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&ty=HTML&h=L&mc=true&=PART&n=pt49.5.393.

[53] https://one.nhtsa.gov/cars/rules/import/fmvss/index.html.

- State inspections requirements include:
  - California Highway Patrol bus maintenance and safety inspection[54] – 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.[55]

- FTA Standards and Testing – buses must meet minimum standards for service life and undergo requirements and maintainability testing for quality control.[56]
- 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.[57]
- *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.[58]
- Fare Collection Facilities
- Transit Cooperative Research Program (TCRP) Fare Policy and Collection – research publications covering funding, implementation, and technology of fare collection.[59]
- APTA Contactless Fare Media System Standards – includes technical specifications, implementation and management guidance, and security standards.[60]

[54] https://www.chp.ca.gov/CommercialVehicleSectionSite/Documents/B%20chp108a.pdf.

[55] https://www.dot.ny.gov/divisions/operating/osss/bus/inspection.

[56] http://www.gpo.gov/fdsys/pkg/CFR-2009-title49-vol7/pdf/CFR-2009-title49-vol7-part665.pdf.

[57] https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-heavy-duty-highway-engines-and-vehicles.

[58] https://www.access-board.gov/guidelines-and-standards/transportation/vehicles/ada-accessibility-guidelines-for-transportation-vehicles-over-the-road-buses.

[59] https://www.apta.com/research-technical-resources/tcrp/tcrp-publications-by-category/.

[60] https://www.apta.com/research-technical-resources/standards/technology/.

SECTION

5

Infrastructure

This section covers fixed guideway infrastructure and common technologies used in their deployment. Infrastructure assets are commonly associated with rail-based modes; here, the category also includes assets associated with busways, aerial ropeways, and waterways. The additional asset classes included in this section are not required for NTD reporting. The category accommodates different technologies, such as the commonly-used steel wheel/steel rail technology, automated guideway transit (AGT), and funiculars, all considered "Track Assets." Specific information about what asset types are required for NTD reporting are included in Table 5-1.

Fixed infrastructure is inclusive of all the underlying guideway, structural elements, and other infrastructure that is necessary for the operation of a public transportation system. These elements can be grouped into four general asset classes, as defined below. This section provides descriptions based on commonly-used terminology and characterizations and where applicable references FTA and/or NTD terminology for ease of use.

- **Guideway** covers all elements supporting a guideway, irrespective of mode, including at-grade, such as a track bed or roadway, and various types of underlying civil works (e.g., bridges, tunnels, retaining walls and ancillary structures); for aerial tramways, this includes towers that hold up cables.
- **Track** refers to the structure that guides the transit vehicle and distributes vehicle dynamic loads to its supporting infrastructure both above and below ground, including standard steel wheel/steel rail technology and other newer systems, such as AGT, that use rubber tires operating over a concrete track.
- **Traction power (power and signal)** encompasses systems for centrally supplying energy to propel vehicles along a guideway. Typically, these 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. Traction power also includes centrally-located mechanical drive systems (usually electrically operated) as used by aerial ropeways and funiculars.
- **Communication and control (power and signal)** encompasses the wayside and onboard equipment used to manage a system and ensure its safe operation, including a variety of hardware such as communications cabling and associated hardware, data radios, on-board train control equipment, and systems that use this infrastructure. Common systems include traffic

management (signaling and dispatching), asset protection, and system monitoring (SCADA).

Table 5-1 provides an example asset inventory hierarchy, including asset class, asset type, and potential asset elements. The asset classes and types are consistent with those defined in the NTD;[61] the elements provide a further level of detail that asset owners may find useful for tracking purposes to better define class-specific features and address the lifecycle management nuances of each asset. Table 5-2 provides examples of Segment Types for each Asset Type. This further classification helps to identify the types of linear segment in which the infrastructure resides at the Asset Type level. Different types of segments may require different approaches to lifecycle management practices.

Table 5-1

Example Fixed Infrastructure Asset Hierarchy

1. Define Asset Class	2. Catalog Asset Types	3. Identify Asset Elements
Guideway	• Aerial Ropeway • At-Grade* • Bridge* • Tunnel* • Waterway	• Surface/Deck • Superstructure • Substructure • Track Bed • Culverts • Perimeter • Retaining Walls • Ancillary Structures
Track	• Tangent • Curve • Transition Curve • Special Trackwork	• Rail • Ties • Fasteners • Welds • Joints • Ballast
Traction Power (Power and Signal)	• Drive System • Distribution • Substation	• Contact System • Equipment • Structure
Communication and Control (Power and Signal)	• Operations Equipment • Systems	• Fixed Signals • Signal House • Cable Infrastructure • Security Equipment • Control Equipment • Communication Equipment • Control/Communication Systems

**reported to NTD*

[61] https://www.transit.dot.gov/ntd/ntd-asset-inventory-module.

Table 5-2

Fixed Guideway Segment Type Examples

<table>
<tr><th colspan="3">Segment Type Examples</th></tr>
<tr><th>Asset Class</th><th>Asset Type</th><th>Segment Type</th></tr>
<tr><td rowspan="5">Guideway</td><td>Aerial Ropeway</td><td>Aerial</td></tr>
<tr><td>At-Grade</td><td>Cut
Embankment
Highway Crossing
Incline
Level</td></tr>
<tr><td>Bridge</td><td>Fixed
Movable</td></tr>
<tr><td>Tunnel</td><td>Bored
Cut-and-cover
Immersed</td></tr>
<tr><td>Waterway</td><td>Canal
Canalized River
Channel</td></tr>
<tr><td rowspan="4">Track</td><td>Tangent</td><td rowspan="4">Main Line
Sidetrack
Siding
Passing Siding
Yard</td></tr>
<tr><td>Curve</td></tr>
<tr><td>Transition Curve</td></tr>
<tr><td>Special Trackwork</td></tr>
<tr><td rowspan="3">Traction Power</td><td>Drive System</td><td rowspan="5">Highway Crossing
Interlocking
Movable Bridge
Running Line
Special Track</td></tr>
<tr><td>Distribution</td></tr>
<tr><td>Substation</td></tr>
<tr><td rowspan="2">Communication and Control (Power and Signal)</td><td>Equipment</td></tr>
<tr><td>Systems</td></tr>
</table>

Ownership and management of fixed infrastructure assets can vary by element. Transit agencies that operate along shared guideway, for example, may be responsible only for a portion of those guideway assets. Similarly, contracted elements, such as power and communication systems, may not be owned by the agency but are still integral to the regular operation of the transit system. When transit agencies own the asset, they are responsible for all maintenance, rehabilitation, and replacement. In some cases, agencies use alternative project delivery models such as Design-Build-Operate-Maintain (DBOM) and Design-Build-Finance-Operate-Maintain (DBFOM) for system expansion projects, and maintenance is assumed by the third-party owner. Regardless of ownership, the design, construction, inspection, and various maintenance and renewal activities may be performed in-house or outsourced.

Federal, state, and local government regulations require many safety-critical infrastructure elements to have regular condition inspections and assessments. For guideway-related assets in particular, there are preventive maintenance activities that minimize risk of failures and ensure the asset reaches (or even exceeds) its design life. Many critical non-guideway infrastructure systems have built-in redundancies and are self-monitoring. Some assets need only minimal maintenance and are simply replaced as they (or their elements) fail.

Because this asset category is so complex, the classification of infrastructure asset inventories can vary widely by element; individual asset subtypes may have separate inventories, maintenance management systems, and business processes. Since asset ownership often varies between infrastructure elements, these systems should be fully integrated and standardized to the degree possible within an agency's enterprise system, and inventory data should be tracked in a single agency-wide database.

Integrated lifecycle management planning that considers all assets together can support a more objective decision-making framework in the planning and procurement phases. Lifecycle management planning also ensures processes are in place that track system performance and support ongoing performance improvement including better reliability and lower maintenance costs.

Lifecycle Management Practices

This section offers suggestions for approaches to managing fixed infrastructure assets and ways infrastructure managers might monitor and manage the entire lifecycle of such assets. Because fixed infrastructure elements have a very long lifecycle, there may be a relatively high level of financial uncertainty and risk over the duration of ownership. Fixed infrastructure assets typically represent some of an agency's largest capital assets, and without timely and effective maintenance, these assets may require more costly rehabilitations to reach their full design life.

The national FTA performance measures for infrastructure are currently limited only to rail infrastructure assets; transit providers are not required to set performance targets for other types of infrastructure assets such as bus rapid transit (BRT) or ferries. Nonetheless, as all infrastructure-related assets are critical in supporting transit system operations, robust lifecycle monitoring is vital to maximizing their utility.

The infrastructure 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 right-of-way, track, traction power, and communications and control systems. In addition, transit agencies should be prepared to provide robust ongoing engineering support to adjust the maintenance approach based on ongoing condition assessments and to address unforeseen technical issues as they arise.

FTA has recognized the link between information systems and infrastructure and that more research is necessary; at the time of this publication, FTA is working to develop more information about systems' relationship to infrastructure. Information systems that used in to operate and manage infrastructure typically have far shorter lifespans and a single asset owner who oversees the lifecycle from procurement to disposal. However, these systems are installed on or integrated with other assets, and so asset management measures may rely on the cooperation of multiple departments. Communications and control 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.
- 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.

Thus, the asset management approach for systems infrastructure elements may be more limited than for guideway, track, and traction power infrastructure elements and 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 asset.

The following sections describe in detail some of the lifecycle activities and considerations that are specific to each of the asset classes within the infrastructure category. These frameworks and suggestions cover the four main aspects of lifecycle asset management:

- Design and Procurement
- Operations and Maintenance
- Capital Rehabilitation and Replacement
- Condition Assessment and Performance Monitoring

Guideway

The most common and costly elements associated with guideway assets are long-lasting structures such as bridges and tunnels. Ancillary structures include retaining walls and smaller infrastructure elements such as culverts and duct banks, which typically have shorter design lives and different asset management requirements.

Bridges and Aerial Structures

Broadly, bridges consist of a superstructure, substructure, foundation, and other non-structural elements 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 sections focus on general principles and approaches related to transit bridge asset management.

Design and Procurement Considerations

Quality assessment and quality control measures such as 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:

- For the design phase, senior engineers review the interaction between materials, structural, geotechnical, drainage, hydraulic, moveable (electrical and mechanical), and scour (foundation erosion) engineering to check design requirements and specifications against applicable codes, models, and standards and to 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. For rehabilitation or replacement projects where the bridge remains in service, QA/QC is a critical safety measure.
- Construction quality control is important, as elements not built to specification may need costly corrections that exceed the project budget. Construction quality control includes materials testing and acceptance, and inspections to verify a contractor's adherence to a plan's details and specifications.

Transit agencies can apply structural health instrumentation either during the construction phase or thereafter to meet specific data needs, particularly 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.

Maintenance and Monitoring Considerations

Transit agencies can own a range of bridge asset holdings. Many heavy rail agencies often have miles of aging viaduct. Commuter rail operations may have high numbers of short-span bridges of similar construction and have only a small number of complex bridge structures. A light-rail system may have only a handful of relatively short-span bridges. It is useful to develop a bridge maintenance plan for more complex bridges to cover inspection protocols, routine maintenance, and issues specific to the bridge. For example, an agency may have an aging moveable bridge, which requires custom fabrication of replacement parts. Agencies can use standard maintenance and inspection plans for more simple structures appropriate to their design and location.

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. In general, basic cyclical maintenance includes cleaning, painting, deck resealing, patching and repair, crack repair, bearing lubrication, and joint replacement and repair.

Preventive maintenance includes activities such as various kinds of waterproofing, cathodic protection, bearing lubrication, and scour countermeasures. Crack repair, joint repair and replacement, and deck patching are considered reactive maintenance.

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, structures are designed and constructed to handle known or expected environmental exposure, and loads during the planning service life if materials are selected accordingly. Most structural deterioration is related to environmental conditions, material defects (or use of incorrect materials), or subjecting the structure to loads in excess of the design load. Sometimes exposure to seismic events, accidents, or other unplanned events can lead to load increases.

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 typically are 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 include repairing or replacing decks (including conversion from open deck to ballast deck bridges), foundations, joints, approaches, or other structural elements (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.

In planning a rehabilitation project, transit agencies should consider several factors:

- **Operability** – 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, its current and forecast condition, and an economic analysis of the rehabilitation's impact on the bridge's total lifecycle cost.
- **Maintainability** – the rehabilitation design should also review maintainability and seek to improve it. Agencies with historic bridges must also consider these heritage assets. Transit agencies can draw on information from past inspections, operations data, review of the bridge design, and planning documentation.
- **Availability** – bridges are typically critical points within 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).

Contractors have developed a variety of techniques to minimize the impact of construction on track availability. These strategies generally focus on either completing key construction steps during out-of-service periods or constructing in-line or off-line temporary structures. In some cases, the agency may be able to test the rehabilitation approach to ensure it is appropriate.

Condition Assessment and Performance Monitoring

Transit 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 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.[62]

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. Guidance on bridge inspection and reporting is published by the FRA (for mainline railroads), AREMA (railroads and transit), and APTA also publishes standards for other fixed structures.

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.

Transit agencies use criteria 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 5-3 provides examples of common bridge condition and performance measures.

Table 5-3

Common 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 follow-up • Load capacity • Cleanliness

[62] https://www.fhwa.dot.gov/bridge/nbis.cfm.

> As bridge maintenance issues are identified, transit agencies often must perform some level of triage in addressing them. 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.

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) Bridge Management (BrM) 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. In other cases, 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 typically consider 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 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 later in a structure's life or as part of the original construction.

Tunnels and Underground Structures

Tunnels are complex long-life assets, often of unique construction, which often 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 guideway. They also hold traction power systems, communications, train control equipment, and tunnel utilities like ventilation, lighting, and water pumps. Tunnels are defined by their length, depth, circumference, local geology, and 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 and structural steel. For systems with electric traction power in particular, addressing tunnel leakage and drainage is critical to maintaining system operation and can mitigate stray current and structural wear from electrical leakage.

Design and Procurement Considerations

Tunnels are assets with extraordinary longevity, and transit agencies must take lifecycle costs into consideration in design. Since replacement is almost never a viable option, construction quality control programs should include relatively high inspection frequency and detail. Following are some key considerations during the tunnel design process:

- It is worthwhile to develop a tunnel waterproofing system with maximal durability to ensure effective drainage, assess the system's maintainability, and institute careful quality control during construction. 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.
- The design process should carefully consider how corrosion will be mitigated, possibly using non-corrosive steel materials (e.g., stainless steel for doors and handrails) and corrosion-resistant pumps and pumping systems. Cathodic protection systems should be carefully specified for durability and maintainability. The corrosion rate must be carefully modeled so that the design robustly accommodates realistic corrosion levels through the design life and up until a rehabilitation project. Critical construction steps, such as the pouring of concrete over reinforcing steel to minimize delamination, needs close construction inspection services.
- Tunnel design should be carefully coordinated with track design. Since transit rail system 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 cause problems in the track profile.
- The design stage should carefully assess how the tunnel will accommodate maintenance, including leak mitigation, track replacement, and cleaning.

Tunnel space is at a premium, as additional space requires a proportional boring investment. However, it is critical to have space available to allow some maintenance work and construction staging to occur without impacting operations.

Maintenance and Monitoring Considerations

Specialized maintenance management systems are available for tunnels. These systems support data collection, planning, and maintenance prioritization and provide a foundation necessary for the implementation of performance-based tunnel maintenance. FHWA and FTA have together created the OneDOT Tunnel Management System for tunnel inspections, condition monitoring, and maintenance logging.[63] 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.

Leaks emanating from structural cracks and construction joints can rust reinforcing steel and cause a delamination within 3–5 years. Within 5–7 years, leaks can cause spalling of the concrete structure. To address this, most systems with a high proportion of below-grade guideway have an ongoing leak mitigation program. 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.

Capital Rehabilitation and Replacement Considerations

As tunnel systems are not typically 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. 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.

Tunnel owners are increasingly retrofitting tunnels with systems to improve operations and operational safety and address low frequency, high impact risks, such as fires and earthquakes. Examples include the installation of more intuitive signage and cues for escape routes and the creation of simplified system control

[63] http://www.fhwa.dot.gov/bridge/tunnel/.

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; a tunnel emergency can affect many 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

For agencies with extensive tunnel assets, it is beneficial 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.

FRA, FHWA, and FTA require tunnel inspections every two years,[64] but transit agencies with extensive tunnel assets can benefit from a more customized approach. 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 such as 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 5-4 provides examples of useful tunnel condition and performance metrics.

Table 5-4

Common 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

[64] https://www.fhwa.dot.gov/bridge/inspection/tunnel/tomie/hif15005.pdf.

Ancillary Structures

Ancillary structures include a range 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:

- Aerial ropeway towers and terminals
- Under-track culverts and crossings
- System-wide 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

In the U.S., safety standards governing aerial ropeways are governed by American National Standards Institute (ANSI) B77.1-2017. At this time, FTA has not developed its own standards related to NTD reporting, safety, or performance. More extensive standards have been developed by the European Union, with recent updates implemented in 2018.

Track

This section addresses only conventional guideways using steel rails. There are, however, additional technologies that use other types of guideways, including rubber-tired systems in various configurations, monorails, and other less common technologies. This complexity means that many two-rail systems are not necessarily directly comparable even if, for example, they are both heavy rail systems. The following section outlines lifecycle management considerations for the design, preventive maintenance, rehabilitation, and condition monitoring of track assets.

Design and Procurement Considerations

Most transit rail systems have a wide variety of track construction choices, whether for commuter, heavy, or light rail. More so than other asset classes, track design is heavily influenced by considerations of the maintenance program to be installed, and can rely on performance testing to influence design and procurement decisions.

- Track and vehicles should be viewed as a system, with wheel and rail profiles and bogie and vehicle suspensions tuned to function harmoniously together. When this is not done, substantially higher vehicle and track maintenance costs and poorer performance will result.
- 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 design lifecycle cost analysis.

Some transit agencies find spending a bit more upfront to use 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 – and extends the overall life of the rail.

- Many performance issues that cannot be cost-effectively addressed through maintenance can be addressed through improved design.
- Engineering or construction defects are significant determinants of track rehabilitation and replacement. Identifying risks in the design and construction phase are crucial to mitigating long-term chronic maintenance problems.

Third-party oversight of contractors can improve 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. 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. 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

Track wear and deterioration is closely tied to a number of use-related factors and age and environmental variables. For a particular track segment, track wear factors include the following:

- Factors related to vehicles and operation (bogie design, wheel profile, 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, rail profile, 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)

Robust data collection and performance measurement and modeling are important strategies to tackle these challenges. For example, 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, smooths the ride, and reduces wear and impact forces on track structure and the rail vehicle. Rail grinding also removes rail head surface cracks, which can grow into detectable flaws and, eventually, broken rails when left unattended.

Performance can be improved when an agency's track maintenance department collaborates with other departments to address asset management. In especially busy systems, transit agencies have little off-line time in which to perform right of way maintenance. Efficiently targeting and bundling maintenance and inspection activities across asset classes and carefully evaluating maintenance procedure effectiveness has proven to be an effective cost control strategy. Similarly, 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.

Capital Rehabilitation and Replacement Considerations

In general, a guideway 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 guideway, rail replacement and track structural work often form a single rehabilitation project. Direct fixation track work can be less intensive.

Transit agencies undertake track replacement directly or through contractors. 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—night work, unless prohibited by local ordinances or union regulations—and on weekends. With tunnel guideway and guideway 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.

Track sections in bridge approaches often require 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

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. Transit operators can make the most of advances in track inspection and maintenance technology to drive performance improvement of their maintenance operations. Track inspections and measurements take three forms:

- **Vehicle-based inspections**, which use onboard sensors on a maintenance vehicle to gather information. Ultrasonic testing and electronic track geometry testing are two common examples of vehicle-based methods.
- **Wayside sensors** can also gather measurements electronically. For example, telemetric devices measure impacts from passing wheel loads, which can be used to identify maintenance needs, such as flat wheels and worn truck elements.
- **In-person inspections** using handheld devices or visual inspection. Track inspection by hi-rail or walking is an example of in-person visual inspection. Part of mandated inspection regimes, these continue to be a vital element towards ensuring safe and reliable operations.

With digital tools now able to handle tasks such as finding rail defects, measuring track geometry, quantifying rail wear, testing track strength, evaluating subgrade conditions with ground-penetrating radar, calculating rail neutral temperature, and assessing timber tie conditions, agencies have more accurate and timely information to manage asset renewal.

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.

Transit agencies can use inspection data to introduce risk-based scoring into their prioritization process to better allocate maintenance resources. Such an approach can vastly improve system safety and reliability. Likewise, these data can be used to assess safe operating speeds for guideway segments to inform FTA performance reporting. Table 5-5 provides examples of track condition and performance measures.

Table 5-5

Common Track Element Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Track	• Element 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 vs. designed minimum travel time* • Noise levels • Rail wear rate by track section • Frequency of recurring perturbation by location

**Must be reported to NTD*

Traction Power

Traction power systems distribute power for electric trolley bus, streetcar, and light rail and heavy rail systems. They also include the centrally powered drive terminals used with aerial ropeways, funiculars, and cable cars.

Traction Power Electrification Systems

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 high-frequency heavy rail systems using exclusive guideway because they tend to have lower installation and maintenance costs but represent safety issues in an unsecured Guideway and are not suitable for high-speed operations (90+ mph). Systems with shared or unsecured rights-of-way use OCS to increase safety, permit high speeds, allow mixed-traffic, and operate over at-grade crossings. Otherwise, the two systems share similar elements and face similar asset management issues and challenges.

Design and Procurement

Traction-power electrification systems are composed of well-established elements, but there are significant design issues that determine system 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 elements to ensure overall system reliability. Vendor involvement can help select an optimal design approach to minimize costs while meeting performance specifications.

Because traction-power electrification systems use high voltage connections and complex electrical systems, 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 robust lifecycle management plan in place to map out the inspection, maintenance, rehabilitation, and replacement needs of system elements and elements. Generally, scheduled or preventive maintenance activities focus on the third-rail and OCS, which experience wear from vehicle use and the surrounding environment. Regular inspections support condition-based maintenance and replacement of these elements.

Although traction power electrification equipment is distributed throughout the guideway, 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 switchgear, cooling systems, batteries, and fire suppression systems. Mobile technology and handheld computers reduce the time needed to enter inspection data. By providing access to documentation and the maintenance management system, electronic devices can also enable technicians to complete a wider range of tasks while more accurately recording work activities.

Capital Rehabilitation and Replacement Considerations

As 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 guideway, rehabilitation projects may require coordination with the public works department for pavement maintenance and rehabilitation and sewer or duct bank 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

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 by identifying defect or failure conditions, energy waste, and stray current. To take advantage of these opportunities, transit agencies need an up-to-date Supervisory Control and Data Acquisition (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 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 now being applied overseas to OCS infrastructure to assess asset defects, wear, corrosion and degradation, OCS geometry, and electrical properties. Table 5-6 lists additional examples of common performance measures for traction-power electrification systems.

Table 5-6

Common Traction Power Electrification System 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 service interruptions

Cable Drive Systems for Aerial Ropeways

Generally, the same asset management practices that are applicable to traction power systems are applicable to cable drive systems. One key difference, however, is that cable-driven transit systems consist of numerous moving parts that must be closely monitored for wear and tear on a daily basis.

Highly integrated systems and complete solutions consisting of terminals, towers, cables, passenger cabins, and control systems are typically acquired from a single vendor. Only a handful of firms produce systems suitable for transit use, and the technology is rapidly advancing to increase capacity and speed, improve reliability, and reduce maintenance requirements. There is little presence of third-party suppliers, so an agency must rely on the OEM for parts, which extends to technical and maintenance support as well, including access to diagnostic and performance data. Furthermore, given the relative scarcity of these technologies in transit applications, the expertise required to manage these systems is highly specialized.

With their level of integration and high risks associated with failure, modern aerial ropeway systems utilize control and monitoring technologies that tend to be more advanced and extensive than other transit modes. Elements have extensive instrumentation, which is used to identify faults and monitor for wear and out-of-specification operation. Table 5-7 lists some examples of performance measures that may be used for cable drive systems.

Table 5-7

Common Cable Drive System Performance Metrics

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Cable Drive Systems	• Spare parts availability • Fail-safe design	• Availability • Mean time between failures • Consumption rates of wear parts; full cost of replacement • Frequency of failure occurrences, including failures with no service interruptions

Communications Infrastructure and Systems

Communications infrastructure enables the various control and management systems that are used to operate a modern transit system. Key applications that utilize this infrastructure include traffic control, security, and SCADA. Although each application consists of a mix of hardware and software, all rely fundamentally on the communications infrastructure. They are often procured separately and have varying lifecycles, costs, and maintenance needs. The following sections discuss the specifics of each of these systems.

Communications Systems

Transit communications systems can span a range of functions and assets. Most commonly, SCADA systems provide the interface between hardware systems and the core communications network and are distributed throughout the transit system. Bus systems typically have few fixed field assets to support remote control and monitoring of SCADA 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 fixed guideway systems, fixed 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 duct banks located along guideways or mounted to poles; radio communication systems may use both transit and non-transit properties to provide appropriate coverage to the service area.

Design and Procurement Considerations

To the extent possible, all of an 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. Some agencies are using Indefinite Delivery and Indefinite Quantity (IDIQ) contracts to lock in supply and prices to help to avoid parts obsolescence.

Transit agencies may also be able to use vendors to provide radio communications on an as-needed 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. Whereas 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.

In some cases, transit agencies may consider sharing communications infrastructure with other local agencies, such as law enforcement and emergency response. Although this can save costs, it 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.

Reassessment of Fare Products

The procurement of a fare collection system provides 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 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.

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 and vehicle configurations.

Maintenance and Monitoring Considerations

Similar to security systems, communication system elements are often low-cost and cheaper to replace than maintain. 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 (COTS) 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.

For many systems, it is possible to replicate the system architecture in the maintenance facility so that serviced elements 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 a 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 elements. Simpler system architectures and modular elements 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.

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 for data bandwidth from system users usually drives 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 5-8 gives some examples of metrics to track ongoing performance of communications, monitoring, and SCADA systems.

Table 5-8

Common Communications, Monitoring, and SCADA System 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

Security

Security systems are deployed onboard revenue vehicles and at fixed facilities, including stations and facilities on the guideway. 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.

Design and Procurement Considerations

Security systems typically interface with public spaces and share many of the general design requirements of passenger facilities. The equipment must be able to sustain temperature fluctuations, weather conditions, cleaning activities, and passenger use typical of the facility. CCTV cameras are typically placed out-of-reach of riders, so they may be difficult to inspect and replace. Whereas 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.

Interoperability is a frequent challenge with security systems. Although new generation security systems often use digital technologies that have significantly cheaper elements and provide higher performance and more features, high installation costs can be a major 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, possibly raising 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 consideration 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 element 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

The transit industry's focus on security issues often has led to higher investment in security assets. Although 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 system 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 element 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.

Elements 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 like security systems that require minimal (relative to other assets) installation, maintenance, and on-site vendor support.

Capital Rehabilitation and Replacement Considerations

The procurement and replacement stages of the asset lifecycle are opportunities to evaluate performance and business requirements, improve system design, and set reliability goals. For many technology systems, transit agencies can rely on simple replacement heuristics, such as whether an asset is no longer under warranty or whether it meets sufficient functional criteria, to cost-effectively plan replacements. Performance monitoring consists mainly of tracking those assets with lower reliability and availability statistics and targeting them for improvement with better elements 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 SCADA systems in passenger facilities.

Condition Assessment and Performance Monitoring

For assets such as security systems, the most common measure of performance is 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 such as 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.

Transit agencies can track security incidents as a measure of security system effectiveness. Careful tracking of incidents by location, type, and other characteristics can help with analysis of security system performance and value. If possible, transit agencies should prioritize identified security needs and address them accordingly, balancing prioritization with costs. Table 5-9 provides examples of various condition and performance measures for security systems.

Table 5-9

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 versus unobserved incident

Traffic Control Systems

For fixed-guideway systems, transit agencies are responsible for all traffic control unless they operate under an agreement with a guideway 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.

Design and Procurement Considerations

As 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. Standardized system architecture helps ensure maintenance staff adhere to standard maintenance procedures and maintain the system's reliability, maintainability, and integrity.

In addition to mapping preventive maintenance, reactive maintenance, and rehabilitation needs, the train control lifecycle management plan should also plan for and prioritize technology upgrades to avoid moving away from a standardized architecture and approach. As with other systems assets, train control systems are subject to a product lifecycle, and new technology and approaches can often make system elements 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 elements 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.

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

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 elements.

In addition to condition-based or reliability-based maintenance, a planned maintenance regime may be required under FRA regulations.

Capital Rehabilitation and Replacement Considerations

Lifecycle management of train control systems typically emphasizes replacement over rehabilitation because of the nature of the assets. Elements 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 anticipate and plan for more technology transitions in accordance with these shorter lifecycles.

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 such as 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.

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 to prevent unsafe conditions and to maintain its manufacturer's warranty (if applicable).

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* has ATC system testing recommendations that 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 two years). Properties outside of FRA jurisdiction should establish inspection frequency and required test results based on AREMA and manufacturer's recommendations.

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) elements may experience only minimal use, often when safety is an important concern. Table 5-10 provides condition and performance metrics for ongoing monitoring of lifecycle management practices.

Table 5-10

Traffic and Vehicle Control 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

Industry Standards

The following list outlines any industry standards associated with the lifecycle of the Fixed Infrastructure asset category.[65]

Bridges

- FHWA National Bridges Inspections Standards – standards are in place to ensure the safety of the traveling public and support the National Bridge Inventory (NBI).[66]
- FHWA Recommended Framework for a Bridge Inspection QC/QA Program – this framework is used to establish consistency and accuracy of inspections and includes procedures for QA/QC and a list of notable practices from other states.[67]
- 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.[68]
- *AASHTO Manual for Bridge Evaluation* and other guides and manuals – manual for bridge inspection that ensures compliance with NBI requirements; other standards cover design, construction, and maintenance.[69]
- FRA Bridge Safety Standards, 49 CFR Part 237 – provides guidance for bridge inspections, capacity, documentation, and qualification requirements for inspectors.[70]
- *AREMA Manual for Railway Engineering* – provides guidelines for the design and maintenance of railroad structures.[71]

Tunnels

- TCRP Synthesis 23, "Inspection Policy and Procedures for Rail Transit Tunnels and Underground Structures" (1997) – a compilation of case studies

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[65] This supplement defines industry standards as requirements, standards, or guidelines that exist currently or are pending.

[66] https://www.fhwa.dot.gov/bridge/nbis.cfm.

[67] http://www.fhwa.dot.gov/bridge/nbis/nbisframework.cfm.

[68] https://www.apta.com/research-technical-resources/standards/rail/.

[69] Available for purchase at https://store.transportation.org/Item/CollectionDetail?ID=179.

[70] https://www.govinfo.gov/app/details/CFR-2011-title49-vol4/CFR-2011-title49-vol4-part237.

[71] Available for purchase at https://www.arema.org/files/pubs/2018_Pub_Order_Form.pdf.

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.[72]

- *FHWA Tunnel Operations, Maintenance, Inspection, and Evaluation (TOMIE) Manual* (FHWA-HIF-15-005, 2015) – provides uniformity and consistency in assessing the physical condition of various tunnel elements. The manual defines tunnel construction and systems, and discusses inspection procedures and documentation.[73]
- *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.[74]
- 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.[75]
- NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems, 2000 ed. – 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.[76]
- *FHWA Technical Manual for Design and Construction of Road Tunnels - Civil Elements* (2011), Section 16 – technical manual with guidelines for planning, design, construction, and rehabilitation of road runnels.[77]

Ancillary Structures

- 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

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[72] http://onlinepubs.trb.org/onlinepubs/tcrp/tsyn23.pdf.

[73] https://www.fhwa.dot.gov/bridge/inspection/tunnel/tomie/hif15005.pdf.

[74] http://www.trb.org/Main/Blurbs/157739.aspx.

[75] http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_525v12.pdf.

[76] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=130.

[77] https://www.fhwa.dot.gov/bridge/tunnel/pubs/nhi09010/tunnel_manual.pdf.

towers, and culverts. Topics covered include inspection practices and controls, and maintenance.[78]

- ANSI B77.1-2017 – Passenger Ropeways – Aerial Tramways, Aerial Lifts, Surface Lifts, Tows and Conveyors – Safety Standard[79]
- Doppelmayr/Garaventa, New Harmonized Standard Series – modifications and other important aspects, Directive2000/9/EC[80]
- Regulation (EU) 2016/424 of the European Parliament and of the Council of 9 (March 2016) on cableway installations and repealing Directive 2000/9/E[81]

Track

- *AREMA Manual of 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. The track section covers design specification, maintenance, and construction.[82]
- AREMA Portfolio of Track Work Plan – consists of plans and specifications of switches, frogs, turnouts and crossovers, crossings, and rails and special track work.[83]
- FRA Track Safety Standards, codified under 49 CFR 213 – minimum safety requirements for specific track conditions, includes maintenance, inspection, and operations.[84]
- 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 elements.[85]
- TCRP Report 155, "Track Design Handbook for Light Rail Transit," Second ed. (2012) – provides guidelines and descriptions for the design of various common types of light rail transit track.[86]

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[78] https://www.apta.com/research-technical-resources/standards/rail/.

[79] https://webstore.ansi.org/Standards/ANSI/ANSIB772017.

[80] http://www.oitaf.org/ref/Innsbruck%202015/Referat%20Mathis.pdf.

[81] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0424&from=EN.

[82] Available for purchase at http://www.arema.org/AREMA_MBRR/AREMA_MBRR/AREMAStore/MRE.aspx.

[83] Available for purchase at http://www.arema.org/AREMA_MBRR/AREMA_MBRR/AREMAStore/Portfolio_of_Track_Work_Plans.aspx.

[84] https://www.gpo.gov/fdsys/granule/CFR-2011-title49-vol4/CFR-2011-title49-vol4-part213.

[85] https://www.apta.com/research-technical-resources/standards/rail/.

[86] http://www.trb.org/Publications/Blurbs/166970.aspx.

Pavement and Roadway

- *Manual for Uniform Traffic Control Devices (MUTCD)* – national standard for traffic control devices (e.g., signage, signals, markings) on any street, highway, bikeway, or private road open to public travel.[87]
- 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.[88]
- *ASTM Standard Guide for Pavement Management Implementation* – guide for process and steps when implementing and operating pavement management systems.[89]
- *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.[90]

Traction Power Electrification

- National Electrical Safety Code – 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.[91]
- NFPA 70, National Fire Protection Agency (NFPA) 70B – the National Electrical Code 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.[92]
- NFPA 130, International Electrical Testing Association (NETA) Maintenance Test Specifications – standard for fixed guideway and transit rail systems that 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

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[87] https://mutcd.fhwa.dot.gov/kno_2009r1r2.htm.

[88] https://www.astm.org/Standards/road-and-paving-standards.html.

[89] https://www.astm.org/Standards/E1889.htm.

[90] https://www.astm.org/Standards/E1166.htm.

[91] http://standards.ieee.org/about/nesc/index.html.

[92] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70 and https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70B.

electrical systems and equipment perform effectively to minimize downtime and maximize life expectancy.[93]

- *AREMA Practical Guide to Railway Engineering* – background and overview information of the specific disciplines of railway engineering design. Section 9 covers design principles, construction practice, and maintenance considerations of railway electrification.[94]
- Institute of Electrical and Electronics Engineers (IEEE) Standard for SCADA and automation systems in substations.[95]

Security

- FTA Safety and Security, Section 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.[96]
- ANSI Workshop on Transit Security Standardization – identifies gap and needs for international standards of public transit security, culminating in a set of recommendations for developing standards. The workshop focused on four topic areas: physical security, command and control, sensor integration, and communications.[97]
- FTA Security and Emergency Preparedness 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.[98]
- National Academies Transportation System Security – studies, reports, guidelines, and practices on general transportation and surface transportation security.[99]
- National Institute of Standards and Technology, *Guide to Industrial Control Systems (ICS) Security* – includes security standards for SCADA and other control systems.[100]

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[93] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=130 and https://www.netaworld.org/standards/ansi-neta-mts.

[94] Available for purchase at http://www.arema.org/AREMA_MBRR/AREMA_MBRR/AREMAStore/Practical_Guide.aspx.

[95] http://standards.ieee.org/findstds/standard/C37.1-2007.html.

[96] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/ftasesc.pdf.

[97] https://share.ansi.org/Shared%20Documents/Standards%20Activities/Homeland%20Security%20Standards%20Panel/HSSP%20Workshop%20Deliverables/Final%20Report%20from%20WSC%20Workshop%20on%20Transit%20Security.pdf.

[98] https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/508_new_top_17.pdf.

[99] http://www.trb.org/SecurityEmergencies/NASecurityProducts.aspx.

[100] https://csrc.nist.gov/publications/detail/sp/800-82/rev-2/final.

Traffic Control

- 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.[101]
  - 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 elements and corresponding rules, standards, or instructions.[102]
- 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.[103]
- *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.[104]
- *APTA Manual of Standards and Recommended Practices for Rail Transit Systems* – Signals and Communications – standards and recommended practices for signal and communication equipment inspection and maintenance.[105]
- Communications/Monitoring/SCADA
- APTA Standard for Radio Communication System Inspection and Testing – standard for inspecting and testing radio communication systems for transit.[106]
- APTA Recommended Practice for Securing Control and Communications Systems in Transit Environments – covers security of SCADA and communications systems.[107]
- NFPA 70: National Electrical Code – used as a benchmark for safe electrical design, installation, and inspection to protect against electrical hazards.[108]

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[101] https://www.gpo.gov/fdsys/granule/CFR-2011-title49-vol4/CFR-2011-title49-vol4-part234.

[102] https://www.gpo.gov/fdsys/granule/CFR-2011-title49-vol4/CFR-2011-title49-vol4-part236.

[103] http://standards.ieee.org/findstds/standard/1474.1-2004.html.

[104] Available for purchase at https://www.arema.org/AREMA_MBRR/AREMAStore/Communications_Signals_2019.aspx.

[105] https://www.apta.com/research-technical-resources/standards/rail/.

[106] https://www.apta.com/wp-content/uploads/Standards_Documents/APTA-RT-SC-S-046-03.pdf.

[107] https://www.apta.com/wp-content/uploads/Standards_Documents/APTA-SS-CCS-RP-001-10.pdf.

[108] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70.

- NFPA 130: Standard for Fixed Guideway and Transit Rail Systems – 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.[109]
- IEEE Standard for SCADA and Automation Systems – lists requirements for SCADA and automation systems in substations.[110]
- Federal Communications Commission (FCC) – a variety of technical standards and rules governing radio communications.[111]
- ANSI – diverse technical standards for materials, testing procedures, and system architectures for diverse electrical systems.[112]
- International Organization for Standardization (ISO) – telecommunication standards, including radio communications and fiber-optic communications.[113]
- National Electrical Manufactures Association (NEMA) – common standards for electrical systems organized by category.[114]

[109] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=130.

[110] http://standards.ieee.org/findstds/standard/C37.1-2007.html.

[111] https://www.fcc.gov/general/oet-technical-documents.

[112] https://www.ansi.org/standards_activities/overview/overview.

[113] https://www.iso.org/ics/33/x/.

[114] https://www.nema.org/Standards/Pages/All-Standards-by-Product.aspx.

SECTION 6

Conclusion

The Transit Asset Management Guide Supplement provides comprehensive information and direction for maintaining assets in a way that prioritizes a holistic consideration of the asset's role in providing transit service. The concepts, ideas, and practices outlined in this Supplement support FTA's vision of incorporating asset management as a business model that prioritizes funding based on asset condition to maintain a state of good repair.

This Guide details the complexities for managing each asset category and provides a broader understanding of contemporary practices and issues involved in asset and lifecycle management. This will be able to inform an agency's long-term planning efforts, financial performance, and service delivery while minimizing costs associated with procurement, operation, maintenance, and rehabilitation and replacement.

This Supplement provides specific considerations for lifecycle management in each asset category and also outlines how an agency can adopt a robust asset management program in line with the objectives outlined in the Guide. Doing so will allow the agency to create a "TAM culture" in which asset management becomes an explicit agency focus and consideration. By identifying what specifications are required as part of NTD reporting, this Guide helps by highlighting what an agency is required to be doing vs. what is possible given a robust asset management program.

To advance an agency's program beyond basic requirements, it must actively engage the following common considerations in everyday decision-making, as detailed in this supplement—design and procurement, operations and maintenance, capital rehabilitation and replacement, and condition assessment. Doing so allows the agency to be proactive when issues arise that may impact the provision of service, thereby prioritizing cost reduction and operational efficiency. These four considerations work in conjunction with each other, and implementing one approach means the agency can more easily begin considering the others. They are organized in order of an asset's lifecycle, starting from the beginning when it is easiest to implement these considerations.

A thorough understanding and incorporation of these considerations into an agency's business practices will help to achieve a robust lifecycle management program that goes beyond basic rule requirements and development of its TAM plan. A robust program expands the agency's focus beyond day-to-day operations, treating asset management as a core agency function. Some elements of this practice can include:

- Prioritizing long-term performance goals over day-to-day service performance measures
- Comparing long-run costs over up-front costs to reduce overall lifecycle cost
- A proactive approach to maintenance and procurement decisions to reduce service and cost disruptions
- Assessing overall condition and risk as determinants in an asset's useful life rather than just an asset's age
- Integrating asset management into all agency operations and practices

There are several benefits of incorporating this TAM culture into an agency. It allows for making better business and financial investments and decisions, aligns the mission of TAM culture across all departments, allows for more flexibility in responding to unplanned changes, and increases stakeholder confidence in your agency. Through these benefits, the condition and performance of the system will improve, with the potential to increase ridership. This will continue to increase the effectiveness and efficiency of the agency while providing better service to passengers.

Successful implementation of a TAM culture requires responsible asset stewardship. This goes beyond the Accountable Executive for the agency's TAM Plan and means an individual or group of individuals act as advocates for asset and lifecycle management throughout all sectors of the agency. These stewards can be any level of staff who have a direct role in promoting a TAM culture within the agency.

Implementation of the techniques and practices explained in this Supplement allow an agency to develop an asset management program that does not simply satisfy reporting requirements, but progresses the agency to a level of proactive and holistic management. Creating a TAM culture is a continuous process that is designed to be adaptive to changes; there is no explicit final step of incorporating asset management as a business practice. The agency will realize its benefits over time and continue to improve and capitalize on the efficiencies of this practice.

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AC	Alternating Current System
ADA	American with Disabilities Act
ANSI	American National Standards Institute
API	Application Programming Interfaces
APTA	American Public Transportation Association
AREMA	American Railway Engineering & Maintenance-of-Way Association
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
ASPE	American Society of Plumbing Engineers
ASTM	American Society for Testing and Materials
ATC	Automatic train control
BOMA	Building Owners and Managers Association
BRT	Bus rapid transit
BrM	Bridge Management
CBTC	Communications-Based Train Control
CCTV	Closed circuit video cameras
DBOM	Design-Build-Operate-Maintain
DBFOM	Design-Build-Finance-Operate-Maintain
DC	Direct Current System
EAM	Enterprise Asset Management
EPA	Environmental Protection Agency
EU	European Union
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GPS	Global positioning systems
HVAC	Heating, ventilation, and air conditioning
ICS	National Institute of Standards and Technology
IEEE	Institute of Electrical and Electronics Engineers
IFMA	International Facility Management Association
IP	Internet protocol
ISO	International Organization for Standardization
KPI	Key Performance Indicator

NCHRP	National Cooperative Highway Research Program
NETA	International Electrical Testing Association
NFPA	National Fire Protection Association
NTD	National Transit Database
OCS	Overhead catenary system
QA/QC	Quality Assurance and Quality Control
RAMS	Reliability, Accessibility, Maintainability and Safety
RCM	Reliability-centered maintenance
SCADA	Supervisory Control and Data Acquisition
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SGR	State of Good Repair
SUV	Sport utility vehicle
SWOT	Strengths, weaknesses, opportunities, and threats and challenges
TAM	Transit Asset Management
TCRP	Transportation Cooperative Research Program
TERM	Transportation Economic Requirements Model
UPS	Uninterrupted power supply

Definitions and Glossary

The following are technical terms used throughout the Supplement that can often be defined differently by different agencies and organizations. For the purposes of this document, these definitions make up a shared lexicon and establish a foundation for the suggestions and alternatives found in each section. These definitions are consistent with those found in the TAM Final Rule and NTD Glossary. Any term that has not been included in the rule or glossary is defined below in the context of this supplement.

Administrative facilities – Buildings that usually house executive management and support activities for overall transit operations, including accounting, finance, engineering, legal, safety, security, customer services, scheduling and planning.

Asset category – The primary or top-level way of cataloging assets. The four asset categories are (1) Revenue Vehicles, (2) Equipment, (3) Facilities, and (4) Infrastructure.

Asset class – The second level of cataloging assets in the asset hierarchy. For example, the two asset classes for the equipment category are (1) Service Vehicles (Non-Revenue) and (2) Capital Equipment.

Asset component – The major parts of an asset that an agency may wish to track separately, which may require increased inspection, specific maintenance activities, or relatively frequent replacement. Tracking assets at the component level may only be helpful with particularly complex or high-value assets.

Asset factor – Revenue vehicle characteristic for which an agency has operational requirements, such as capacity, speed, acceleration, braking, and loading time.

Asset subcomponent – A classification level below asset component that can be used to further refine the asset component classification, in order to better meet individual agency data classification needs. Tracking assets at the subcomponent level may only be helpful with particularly complex or high-value assets.

Asset subtype – A classification level below asset type that can be used to further refine the asset type classification, in order to better meet individual agency data classification needs.

Asset type – Secondary to asset class, asset types specify the vehicles within each class.

Automobiles (AO) – Passenger cars, up to and including station wagons in size; excludes minivans and anything larger.

Buses (BU) – Rubber-tired passenger vehicles powered by diesel, gasoline, battery or alternative fuel engines contained within the vehicle. Vehicles in this category do not include articulated, double-decked, or school buses. Includes cutaway/body-on-chassis vehicles for urban reporting.

Capital equipment – Assets used for communications, fare collection, maintenance, and security, as well as office furniture, IT hardware/software, facility equipment, bus shelters, wayside equipment, power & electricity distribution, assorted passenger amenities, works of art, and all other tangible or intangible assets that have useful lives over one year. Capital equipment consists of assets that are semi-permanent and are integrated into larger assets, can be removed or replaced as needed, and usually have a shorter service life than that of the larger asset.

Facilities – Structures that enclose or support maintenance, operations, administrative, and public spaces.

Facility systems – Non-structural elements required to operate a building or facility, including HVAC, electrical, plumbing, drainage, fire protection, safety and security, landscaping, and others.

Fixed equipment – Vehicle lifts, fueling equipment, storage tanks, elevators and escalators, and vehicle washers.[115]

Fixed-guideway vehicles (FG) – Fixed guideway is a public transportation facility that is using or occupying: a separate right-of-way, rail, fixed catenary system, passenger ferry system, or bus rapid transit system.

Heavy rail (HR) – A transit mode that is an electric railway with the capacity for a heavy volume of traffic. It is characterized by rapid acceleration rail cars operating on fixed rails, separate rights-of-way, sophisticated signaling, and high platform loading.

Light rail (LR) – A transit mode that typically is an electric railway with a light volume traffic capacity compared to heavy rail (HR). It is characterized by passenger cars operating in short, one or two car trains, on fixed rails, in a separate right-of-way, with vehicle power drown from overhead.

[115] 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.

Maintenance – Preventive interventions that typically require smaller financial and labor investments, usually carried out according to manufacturer guidelines with the goal of extending the overall lifecycle of the asset.

Maintenance Facilities – Maintenance facility where mechanics, machinists, and other maintenance personnel perform preventative maintenance, daily service and inspection, and/or corrective maintenance activities on revenue vehicles to keep them in-service.

Other Rubber-Tire Vehicles – Encompasses multiple types of motorized passenger vehicles such as automobiles, minivans, pickup trucks, motorcycles, rail cars, and buses intended for roadway or rail travel.

Paratransit vehicle – Vehicles used to provide passenger transportation which is more flexible than conventional fixed-route transit but more structured than the use of private automobiles. Paratransit includes demand response (DR) transportation services, shared-ride taxis, car-pooling and vanpooling (VP), and jitney (JT) services. Most often refers to wheelchair-accessible, demand response (DR) service.

Passenger facilities – Significant structures with a separate right-of-way (ROW). Street stops or passenger shelters do not constitute a passenger station. Passenger stations include all transportation, transit or transfer centers, park-and-ride facilities, and transit malls if they have an enclosed structure (building) for passengers for items such as ticketing, information, restrooms, concessions, and telephones.

Rehabilitation – Rehabilitation refers to the rebuilding of revenue vehicles to original specifications of the manufacture. Rebuilding may include some new components but has less emphasis on structural restoration than would be the case in a remanufacturing operation, focusing on mechanical systems and vehicle interiors.

Replacement – The replacement of revenue vehicles having reached the end of a minimum normal service life.

Revenue vehicles – The floating and rolling stock used to provide revenue service for passengers.

Rolling stock – Transit vehicles such as buses, vans, cars, railcars, locomotives, trolley cars and buses, and ferry boats, as well as vehicles used for support services.

Steel Wheel Vehicles – Any heavy-duty vehicle, including specialized track equipment used for maintenance, construction, or repairs of track assets, as well as specific types of heavy equipment for construction or maintenance purposes.

Streetcars (SR) – This mode is for rail transit systems operating entire routes predominantly on streets in mixed-traffic. This service typically operates with single-car trains powered by overhead catenaries and with frequent stops.

Structural elements – Building components such as a roof, windows, and foundation, fencing, and impervious surfaces.

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