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FEDERAL TRANSIT ADMINISTRATION

Managing Railcar Maintenance

A Primer on Practices and Improvement Opportunities for the U.S. Transit Industry

SEPTEMBER 2013

FTA Report No. 0043
Federal Transit Administration

PREPARED BY

PARSONS BRINCKERHOFF

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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

This report surveys the state-of-practice of transit railcar maintenance management and fleet management practices. It emphasizes a lifecycle management approach to fleet management. It also emphasizes the role of performance improvement programs and introduces Reliability-Centered Maintenance and Total Productive Maintenance as key examples of performance improvement approaches. The report also covers planning and performance measurement for rail fleet maintenance, as well as the role of supporting business processes and systems in railcar maintenance, including new vehicle procurement, facility upgrades, maintenance information systems, and purchasing and materials management.

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PREFACE

The federal government has identified preserving and improving the condition of transit rail assets, including railcars, as a critical requirement to maintain the safety and performance of major transit systems (1) and has prioritized this objective in the most recent transportation appropriations legislation, Moving Ahead for Progress in the 21st Century (MAP-21). The Federal Transit Administration (FTA) has reported that there is an estimated backlog of $50 to $80 billion in deferred maintenance and replacement needs for the United States' public transit assets, of which the great majority is rail-related (2). Moreover, 25 percent of national rail transit assets, including rolling stock, were in marginal or poor condition. The federal government has provided funding for the purchase of 66 percent of the active transit railcar fleet[1] and therefore has a strong interest in ensuring that these assets are well maintained and reach their planned service lives while meeting safety, performance, and cost-effectiveness goals.

Improvement in railcar fleet availability, reliability, condition, and cost requires a whole lifecycle management perspective. As stated in the FTA Asset Management Guide:

> Transit asset management is a strategic and systematic process through which an organization procures, operates, maintains, rehabilitates, and replaces transit assets to manage their performance, risks, and costs over their lifecycle to provide safe, cost-effective, and reliable service to current and future customers." (3)

A transit agency's railcar maintenance department is typically responsible for carrying out the majority of lifecycle management activities for the railcar fleet and is involved every aspect of a vehicle's lifecycle. For instance, the railcar maintenance department provides oversight of and input to the design and procurement processes to ensure the reliability and maintainability of the railcar's design and the quality of its manufacture. Once the fleet enters service, the railcar maintenance department is responsible for the selection cost-effective maintenance strategies, workforce development and maintenance planning, performance monitoring, and ongoing performance improvement. Moreover, fleet maintenance is a major cost center for transit agencies, typically making up 20 percent of the operating budget (4).

To advance the effectiveness of the transit industry's railcar maintenance practices, this report presents the results from research and assessment of the state-of-the-practice. It provides a primer for maintenance managers to improve their control over railcar lifecycle costs while also raising service quality. To accomplish this, the report:

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[1]Based on 2011 NTD data.

- Outlines the challenges the industry faces and the benefits of improving an agency's railcar maintenance management practices
- Introduces various railcar maintenance management approaches and improvement strategies, when they are best utilized, and how they can drive ongoing performance improvement for the railcar fleet
- Describes the key planning activities that railcar maintenance managers employ to support high quality fleet management
- Outlines how railcar maintenance managers can use performance measures that link maintenance decisions to the railcar's overall lifecycle management
- Presents how maintenance managers can develop and maintain a productive, motivated, and engaged workforce focused on quality and continuous improvement
- Describes how maintenance managers can help ensure the effectiveness of supporting business processes

This report presents accessible lessons-learned based on research into "hands-on" experience related to all aspects of railcar maintenance management. The report includes examples of practices that agencies have successfully applied and is intended to provide practical guidance for transit agencies interested in improving their railcar maintenance performance. The audience for this report is any person with a leadership position in the railcar maintenance function or anyone who is interested in a broader understanding of contemporary practices and issues involved in the management of railcar maintenance.

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

Sources

1. Government Accountability Office. 2011. FTA programs are helping address transit agencies' safety challenges, but improved performance goals and measures could better focus efforts. Report to the Committee on Banking, Housing, and Urban Affairs, U.S. Senate. Washington, DC: U.S. Government Accountability Office, January 31.
2. U.S. Department of Transportation, Federal Transit Administration. 2010. 2010 National State of Good Repair Assessment. Washington, DC: Federal Transit Administration, June.
3. Rose, David, et al. 2013. *Asset Management Guide*. Washington: U.S. Department of Transportation Federal Transit Administration,.
4. Giacobbe, Robert. 2013. Is public transit ready for reliability-centered maintenance? 2013 APTA Rail Conference. Philadelphia, PA: American Public Transportation Association, June 4.

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- Los Angeles County Metropolitan Transportation Authority
- MTA Long Island Railroad
- MTA Metro-North Railroad

ABSTRACT

This report surveys the state-of-practice of transit railcar maintenance management and fleet management practices. It emphasizes a lifecycle management approach to fleet management. It also emphasizes the role of performance improvement programs and introduces Reliability-Centered Maintenance and Total Productive Maintenance as key examples of performance improvement approaches. The report also covers planning and performance measurement for rail fleet maintenance, as well as the role of supporting business processes and systems in railcar maintenance, including new vehicle procurement, facility upgrades, maintenance information systems, and purchasing and materials management.

EXECUTIVE SUMMARY

This research report is intended to advance the effectiveness of the transit industry's railcar maintenance practices through improved management. It presents the results of research and transit agency interviews regarding the state of the practice in railcar maintenance management in the United States transit rail industry, as well as internationally. It covers strategies and case studies that transit agency railcar maintenance departments can apply to better manage railcar lifecycle costs, risks, and performance.

The report will be of value to agency staff new to railcar maintenance, to railcar maintenance staff new to management, and to railcar maintenance staff interested in performance improvement practices. It provides an introduction to key management concepts and processes in railcar maintenance. The report builds on the lifecycle management framework outlined in the FTA's *Transit Asset Management Guide and Asset Class Supplement* (1). The Guide offers specific approaches to support short-term performance improvement and to lay the foundation for the long-term success of a transit agency's railcar maintenance program.

Railcar Lifecycle Management

Effective lifecycle management drives successful service delivery and financial performance by minimizing the cost to procure, operate, maintain, rehabilitate, and replace an asset while meeting or exceeding established performance commitments for both the asset and the transit system as a whole. As shown in Figure ES-1, the railcar maintenance department should be involved in all aspects of a railcar's lifecycle to achieve the desired fleet performance.[2] For example, during the design/procurement lifecycle stage, requirements and design review by the railcar maintenance department can help ensure new vehicles are designed to be cost-effectively maintained. Once new railcars enter service, the agency's railcar maintenance department is responsible for ongoing preventive and reactive maintenance and rehabilitations. The department's maintenance program ensures the transit agency can meet its ongoing fleet safety, availability, service quality, and cost goals. Only through sustaining a quality maintenance program can the agency manage the fleet to minimize lifecycle costs while ensuring quality transit service for customers.

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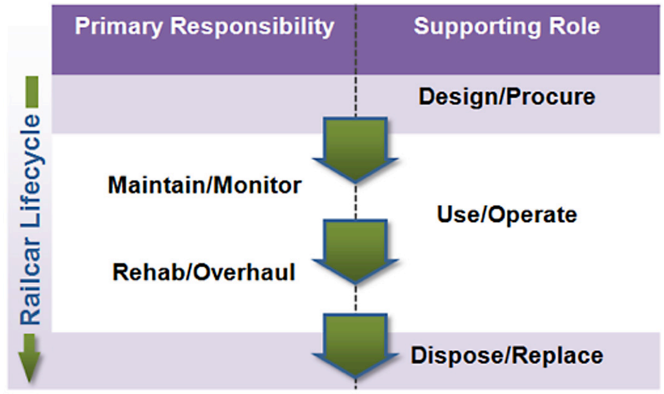
[2]FTA's *Asset Management Guide* (1) covers best practices for managing transit assets across the lifecycle.

Figure ES-1

Railcar Maintenance Department Lifecycle Management Responsibilities



This report expands on the summary of railcar lifecycle management practices provided in the *FTA's Asset Management Guide Supplement* (1) with a focus on the "maintain/monitor" step within the railcar lifecycle. The report also covers the railcar maintenance department's role in each of the other steps of the vehicle lifecycle. The whole lifecycle perspective is a critical component of effective railcar maintenance management. Railcar maintenance managers fulfill the role of "owners" of the rail fleet assets, with final responsibility for rolling stock availability, reliability, cost, and passenger comfort.

Research Approach

This report incorporates findings from a literature review and an analysis of NTD 2011 data, as well as examples compiled directly from the selected transit agencies around the United States. The transit agency examples are incorporated in the report to demonstrate how and where particular maintenance management concepts and strategies have been deployed effectively. When possible, the case studies highlight strategies employed, outcomes, and lessons learned, such as risks and success factors.

Sections Overview

The following describes the objectives and contents of each section:

Section 1: Introduction to Railcar Maintenance Management – This section describes railcar lifecycle management activities and emphasizes the link between decisions across the lifecycle and maintenance requirements. It describes the state of the national transit rail fleet and industry, the challenges the industry faces related to fleet management, and the benefits of improving an agency's railcar maintenance management practices.

Section 2: Overview of Railcar Maintenance – This section introduces contemporary railcar maintenance management strategies in more detail, including various types of preventive maintenance. The section describes how each maintenance strategy is best applied and its role in the overall maintenance program. It also discusses alternative business models for railcar maintenance, including contracted maintenance.

Section 3: Improvement Strategies – This section focuses on performance improvement strategies for railcar maintenance. It addresses the identification of opportunity areas for improvement. The section introduces two major performance improvement frameworks—Reliability-Centered Maintenance and Total Productive Maintenance, together with supporting analysis and improvement methods. The section also explains how and when to use these management approaches to drive ongoing performance improvement of the railcar fleet.

Section 4: Planning Processes – This section describes the planning activities that railcar maintenance managers should be supporting at all levels of an agency—from agency-wide strategic planning to capital planning to day-to-day maintenance staff work plans. This section covers the importance of planning processes for the direction and implementation of the overall fleet maintenance program and the ongoing performance and condition of the railcar fleet.

Section 5: Performance Measurement – This section describes how railcar maintenance managers can use performance measurement to monitor implementation of the maintenance program and align complex operations with overall department and agency goals. The section covers how to select performance measures, establish a baseline, communicate performance data, and use performance measures to support decision-making.

Section 6: Workforce Training and Organizational Development – This section discusses challenges related to management of the railcar maintenance workforce and strategies and opportunities for improving workforce skills and performance. It discusses state of the practice around training, knowledge management, and creating a maintenance culture focused on productivity and quality.

Section 7: Supporting Processes and Systems – This section focuses on the supporting processes and systems on which a railcar maintenance department relies to effectively carry out its mission. Chief among these are the procurement, maintenance facility improvement projects, materials management, and information technology functions, which may be hosted in other departments but are integral to the railcar maintenance program's work. This section explores the role of each of these functions in railcar maintenance and presents management strategies and methods to ensure their effectiveness and support their improvement.

Sources

1. Rose, David, et al. 2013. *Asset Management Guide*. Washington: U.S. Department of Transportation Federal Transit Administration.

SECTION 1

Introduction to Railcar Maintenance Management

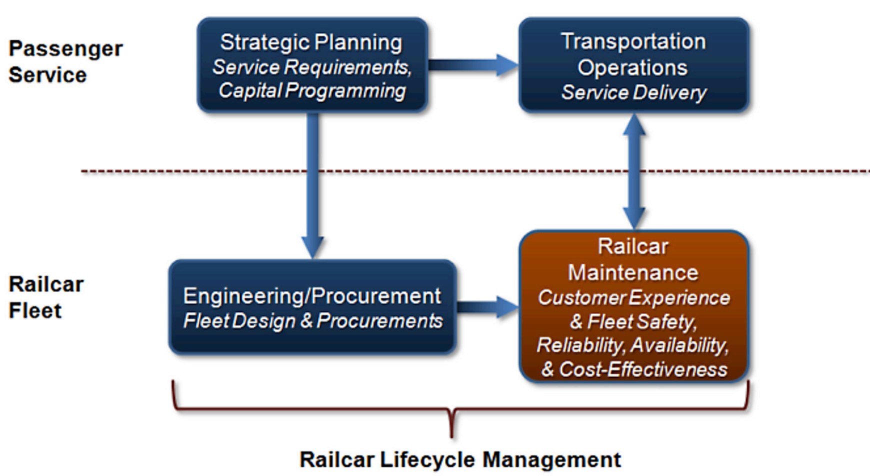
This section describes railcar lifecycle management activities and emphasizes the link between decisions across the lifecycle and maintenance requirements. It describes the state of the national transit rail fleet and industry, the challenges the industry faces related to fleet management, and the benefits of improving an agency's railcar maintenance management practices.

The transit industry in the U.S. today is devoting considerable management and technical attention to improving service reliability and the customer experience. The reliability and condition of railcars has a significant impact on the overall customer experience (1),(2), as well as on fleet costs. The focus on service quality and reliability occurs at a time when many transit agencies face increased expectations from passengers and policy-makers for more business-like practices and increased accountability for performance and costs. With the enactment of MAP-21,[3] safety and performance management reporting requirements have been strengthened, and there is renewed industry focus on asset management, in part spurred by the requirements to develop asset management plans.

Figure 1-1 outlines the railcar maintenance department's role in the overall agency's business model. High-level planning processes determine the level of service and fleet requirements. In support of these requirements, the railcar maintenance department is responsible for the fleet's lifecycle management—including procurement, engineering, and maintenance—and its readiness for revenue service. Through its stewardship of the fleet, the railcar maintenance department is responsible for managing the fleet's cost and performance.

Figure 1-1

Role of Railcar Maintenance in Overall Agency Business Model



[3]http://www.fta.dot.gov/map21/, February, 2013.

Our research finds that best practice is to make investment decisions throughout the railcar lifecycle that consider maintenance requirements and costs. This approach depends on data-driven decision-making, improved integration across maintenance and support functions, the engagement of the maintenance workforce at all levels, and a focus on the customer experience, especially with respect to railcar condition and performance.

The industry's spotlight on improved asset management practices has maintenance managers working to transition from a "find and fix" or "reactive" maintenance mode to a "predict and prevent" or preventive maintenance mode. Reducing reactive maintenance goes beyond merely following preventive maintenance protocols and encompasses greater development and use of inspection techniques, monitoring and diagnostics technologies, statistical analysis, and quality assurance measures to improve preventive maintenance efficiency and effectiveness.

Maintenance management defined. In this report, "maintenance management" refers to the planning, implementation, and oversight of railcar maintenance, with an emphasis on a lifecycle management perspective. Maintenance management involves strategies, methods, and approaches that can help the agency to operate more efficiently and effectively within the constraints of the transit environment. It covers both oversight and direction of railcar maintenance processes and resources as well as interface with and support for other critical agency processes—such as vehicle procurement, inventory management, and information systems management—which contribute to the railcar maintenance program's overall performance and success. "Maintenance management," when referenced in this document, addresses how to apply the available resources most productively. It does not refer to activities that address insufficient resources (e.g., lack of funding and staff) or inadequate facilities and equipment.

Maintenance managers play a critical role in railcar lifecycle management: they are responsible for ensuring that their railcar fleet is maintained at a level that ensures safe, reliable, and cost-effective operations. For some agencies, this responsibility falls under the Chief Operating Officer or Chief Mechanical Officer; for others, it is a manager position in the agency's Engineering and/or Maintenance department. Depending on the level of responsibility given to the maintenance manager, this position is often responsible for supporting other aspects of the railcar's lifecycle as well, including new vehicle procurements and major rehabilitation programs. These upper managers—together with the superintendents, supervisors, and foremen who support them—are increasingly applying more sophisticated maintenance management strategies and approaches to raise their operations' productivity and improve work quality.

This section provides context for the rest of the research report. It surveys the state of the U.S. transit industry's railcar fleet, including its continued growth and change in composition, as well as the increasing number of smaller transit rail operators. The section then outlines the role of maintenance within the railcar lifecycle. Next, the section presents the challenges railcar maintenance programs face and the potential benefits associated with improved railcar maintenance management. Finally, it provides an overview of the other report sections.

Railcar Vehicles in the U.S. Transit Industry

Data from the Federal Transit Administration's (FTA) NTD (NTD) shows that rail transit is growing as a transportation mode in the United States, both as a result of existing rail transit systems expanding and of transit agencies building new rail transit systems. This section surveys these growth trends and other key trends in the industry to provide context to the rest of this research report.

Transit railcars are defined in this report as fixed-guideway vehicles supporting revenue service. These include locomotives, unpowered passenger cars, and powered passenger cars. The latter railcar type is classified either as an electrical multiple unit (EMU), diesel multiple unit (DMU), or hybrid multiple unit based on its propulsion system.

Transit railcars differ not only based on their propulsion but also on the type of transit system they serve. NTD classifies systems into commuter rail, heavy rail, light rail, streetcar, and hybrid rail. Each of these systems is described in Table 1-1 below.

Table 1-1

NTD Rail System Categories

System Type	Description	Applicable Vehicle Types
Commuter Rail	Fixed guideway rail service operating on either old freight railways, or on tracks that are shared with freight railways, Amtrak, or both. The service is characterized by relatively long distances between stops, for service primarily connecting a central city with outlying suburbs and cities. The service usually has grade-crossings with roadways.	Locomotives Passenger coaches Diesel multiple units Electric multiple units Hybrid multiple units
Heavy Rail	An electric railway that operates local service in exclusive right-of-way. The service is characterized by long trains of six to eight cars or more and by relatively short distances between stops for local service within a city and the immediate suburbs. The nation's traditional subway systems are classified as heavy rail.	Electric multiple units
Light Rail	An electric railway that operates local service, at times in mixed traffic with road vehicles, or has grade crossings with roadways. The service is characterized by short trains of one to four cars and by relatively short distances between stops for local service within a city and the immediate suburbs.	Electric multiple units Hybrid multiple units
Hybrid Rail	Rail systems primarily operating routes on the National Rail System, but not operating with the characteristics of commuter rail.	Diesel multiple units Hybrid multiple units
Streetcar	Rail systems operating routes predominantly on streets in mixed-traffic. This service typically operates with single-car or articulated trains powered by overhead catenaries and with frequent stops.	Modern streetcars Historic streetcars

Source: NTD (3)

The 2011 NTD reported that, there are 74 heavy rail, commuter rail, light rail, streetcar, and hybrid rail transit systems in the United States, operated by 55 separate transit agencies and together composing a national fleet of 20,684 active railcars in Fiscal Year (FY) 2011.[4] The active railcar fleet is composed of 54 percent heavy rail, 34 percent commuter rail, 10 percent light rail, and a small number of streetcar and hybrid rail vehicles. Table 1-2 summarizes the nation's active railcar fleet.

Table 1-2

Composition of Active Railcar Fleet in the United States, 2011

Transit Mode	Revenue Vehicles in Active Fleet	Mean Vehicle Age	Mean Railcar Capacity
Heavy Rail	11,272	20	157
Commuter Rail	7,121	20	181
Light Rail	1,975	16	142
Streetcar	272	42[5]	78
Hybrid Rail	44	9	209

Source: NTD

The 10 largest transit agencies by fleet size reflect the diversity of the nation's active railcar fleet and operational practices. As shown in Table 1-3, the top 10 agencies in terms of fleet size serve 6 metropolitan areas and account for 79 percent of the nation's active transit railcar fleet. Overall, average vehicle age ranges from as old as 40 years (Staten Island Rapid Transit Operating Authority) to as new as one year (Port Authority Trans-Hudson Corporation).[6]

Table 1-3

Summary of Active Railcar Fleet in the United States by Agency, 2011

Agency	Number of Cars	Average Vehicle Age[7]	Total Vehicle Maintenance Cost ($M)[8]	Maintenance Labor Hours per Vehicle
MTA New York City Transit	6,282	18.0	$620.9	1,354
Northeast Illinois Regional Commuter Railroad Corporation (Metra)	1,434	28.9	$123.8	1,516
New Jersey Transit Corporation	1,347	17.1	$217.3	2,081
MTA Long Island Rail Road	1,165	9.7	$332.1	3,475
Massachusetts Bay Transportation Authority	1,146	22.3	$162.2	1,012
Chicago Transit Authority	1,142	28.8	$88.9	1,068
Metro-North Commuter Railroad Company	1,137	20.2	$222.4	2,513
Washington Metropolitan Area Transit Authority	1,108	21.5	$153.2	1,800
Southeastern Pennsylvania Transportation Authority	907	28.2	$92.9	1,702
San Francisco Bay Area Rapid Transit District	668	13.7	$91.2	1,443

Source: NTD

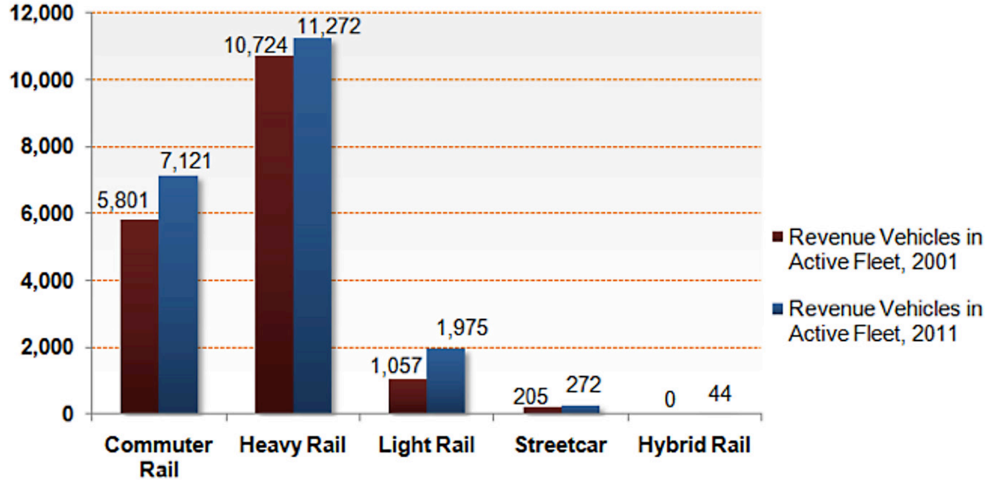
[4] Though catalogued in the NTD, railcars belonging to the Alaska Railroad are not included in this analysis as, at present, their service more closely resembles intercity passenger rail rather than commuter rail or transit service.
[5] Includes historic vehicles.
[6] Note that several agencies also operate historic streetcars, some over a century old, which will never be retired and, if included in the average age estimates, would skew them significantly.
[7] In some cases, transit agencies have reported remanufactured or rehabilitated cars as new, leading to a lower mean age calculation.
[8] Vehicle maintenance costs are the sum of all NTD vehicle maintenance operating expense categories by transit system.

Even within the top 10 agencies, there is dramatic variation in average vehicle age and maintenance costs and maintenance labor hours per vehicle. Within the NTD data, few variables explain more than a small portion of this variation. Statistical analysis of NTD data conducted as part of this research finds that the mean miles per vehicle and the rail transit mode offer some explanation of the differences in agencies' productivity (measured by maintenance labor hours per vehicle), efficiency (measured by maintenance cost per vehicle), and effectiveness (measured by mean distance between failures). As would be expected, higher levels of railcar use (measured by vehicle miles) result in higher maintenance costs, and the technological differences among the modes are an obvious reason for the variation in performance by mode. However, most variation in railcar maintenance performance among agencies appears to be related to organizational factors not quantified in NTD rather than fleet technology and use factors. This conclusion underscores the importance of effective management of the railcar maintenance program, the subject of this report.

Rail transit is growing as a mode, with the largest net additions to the U.S. railcar fleet occurring in smaller transit agencies and commuter, light rail, and streetcar services. Figure 1-2 shows the growth in the national railcar fleet between 2001 and 2011 by mode, representing an overall increase in fleet size of 16 percent. The greatest relative increase was an 87 percent rise in the number of active light rail vehicles, whereas the commuter rail fleet had the greatest absolute growth: an increase of 1,320 vehicles. Smaller transit agencies were responsible for a slight majority of the total increase in the U.S. railcar fleet. While the 10 largest agencies added nearly 1,400 vehicles, the remaining agencies added more than 1,500, increasing their share of the national railcar fleet from less than 16 percent to nearly 21 percent. From 2001 to 2011, the number of U.S. transit agencies with passenger rail operations grew from 44 to 55. These trends mean that the U.S. will have an increasingly diverse transit rail fleet with respect to rail transit mode and vehicle technology, distributed among a greater number of geographies. The implication is that railcar procurements will be more numerous but smaller in size. To sustain this growing fleet, U.S. transit agencies will need a concomitant increase in resources dedicated to fleet management, including preventive and corrective maintenance and rehabilitations.

Figure 1-2

Growth in the Number of U.S. Railcar Vehicles (2001 to 2011)

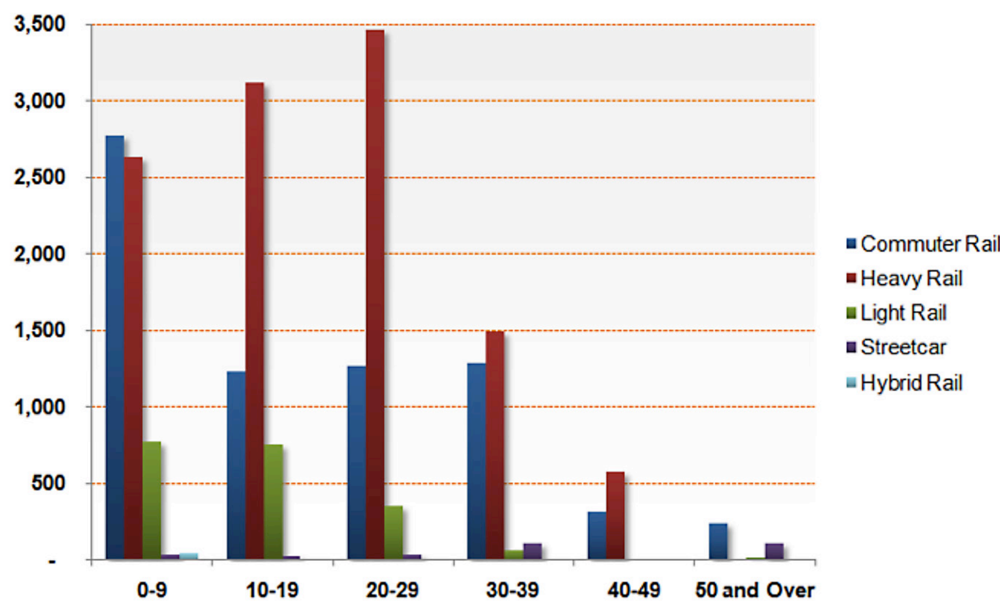


Source: NTD

The U.S. transit railcar fleet will require significant and growing investments in rehabilitation and replacement in the coming decades due to its age and increased size. Figure 1-3 provides the age distribution of the transit fleet by 10-year cohort. The average age of the U.S. transit agencies' railcar vehicles skews younger with most vehicles being less than 30 years old, which reflects the fleet's ongoing growth. The particularly large skew of the light rail and commuter rail fleets toward younger vehicles reflects the higher than average growth rates in these modes, while the heavy rail fleet has slower fleet growth and a flatter age distribution. Of the vehicles that are more than 50 years old, these are mostly due to commuter rail passenger coaches and historic streetcars. The larger size of younger age cohorts underscores the need for growing investment levels in fleet maintenance, rehabilitation, and replacement in the coming decades to sustain the national fleet.

Figure 1-3

Number of Active Railcars in the United States by Age Cohort (2011)

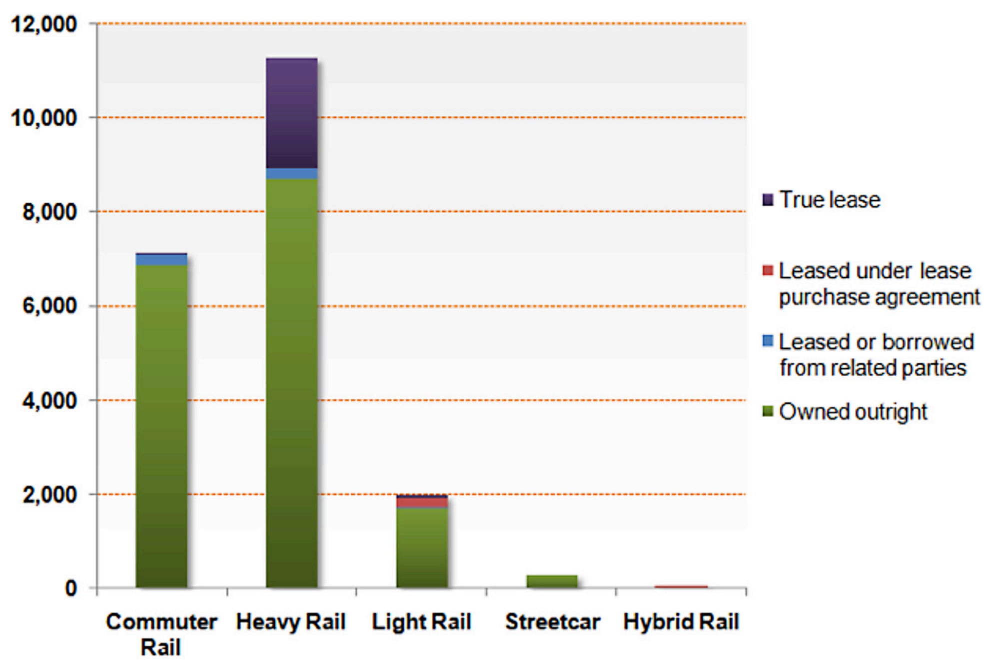


Source: NTD

The vast majority of railcars are owned outright by the transit agency with a small proportion leased. Figure 1-4 shows the number of railcars in the U.S. fleet by mode and ownership status. The majority of the U.S. transit agencies' railcar vehicles are owned outright. The only major exception is 2,351 heavy railcar vehicles (or 21% of all U.S. heavy rail vehicles). These are considered to be "true leases," which, as defined by the NTD, means that the lease covers the total cost of the capital asset plus interest. At the end of the lease the capital asset is still owned by the lessor (entity providing the capital asset) rather than the transit agency. The low proportion of leased vehicles indicates that U.S. transit agencies have not embraced some of the alternative business models used in other countries to manage transit rail fleets, where transit and intercity rail operators more commonly use a variety of lease arrangements for their fleets (4),(5).

Figure 1-4

Number of Active Railcars in the United States by Ownership Status (2011)



Source: NTD

The NTD provides the following definitions of the vehicle lease agreements included in the previous figure:

> Leases are payments for the use of capital assets not owned by your transit agency. There can be different leasing arrangements involving:
>
> Purchase lease agreements… are financing plans that enable your transit agency to acquire (own) the capital asset at the end of the lease, sometimes with an additional payment due. The property covered by such leases may or may not have been recorded as owned assets, either during or after the period of the lease, your

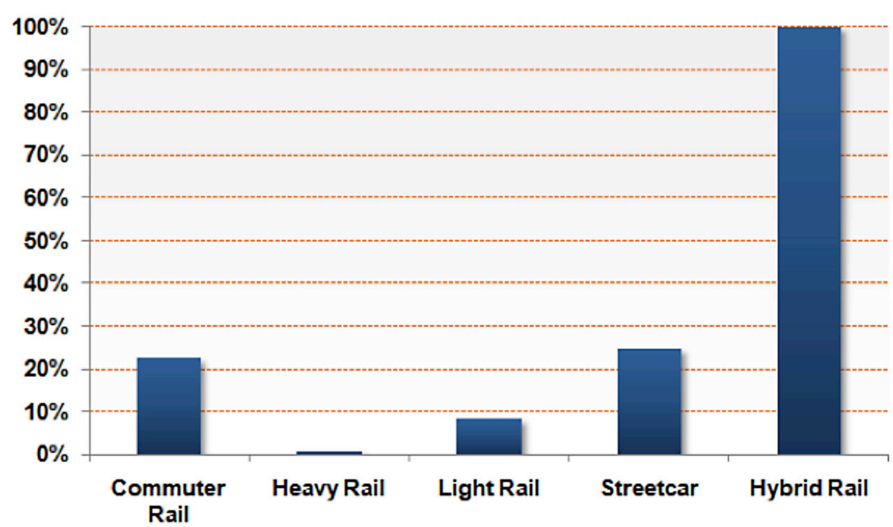
transit agency's internal accounting records. If purchase leases have not been capitalized in your transit agency's internal accounting records, this category includes the lease payments for the purchase lease agreement. If the lease has been capitalized in the internal accounting records of your transit agency, you should report it as it has been accounted for internally.

Related parties lease… where the terms and amount of payments by your transit agency are substantially less than in a true lease because your transit agency is related to the lessor. For example, a transit agency may lease surplus equipment from another transit agency or local government (3).

Outside of heavy rail systems, contracted maintenance is widely used, especially by smaller transit rail systems. Overall, it is common for agencies to contract out their maintenance. In nearly every case where a transit agency contracts maintenance, it also contracts operations, often but not always to the same contractor. All hybrid rail systems contracted maintenance, and 57 percent commuter rail systems use contracted maintenance. Figure 1-5 shows the percent of the fleet maintained by contractors by mode, and Figure 1-6 shows the total number of vehicles maintained by contractors for each mode. In absolute terms, commuter rail systems rely most on contracted maintenance, accounting for 82 percent of the 1,942 railcars maintained by contractors and 17 of the 26 transit rail systems using contracted maintenance. Contracting the vehicle maintenance of heavy rail, light rail, and streetcar vehicles is less common. In part, these figures reflect the tendency of smaller agencies, which represent more hybrid rail and commuter rail systems, to contract service. In fact, contracted service negatively correlated with the size of the rail system's active fleet. Agencies with newer transit rail systems are also more likely to contract for vehicle maintenance services.

Figure 1-5

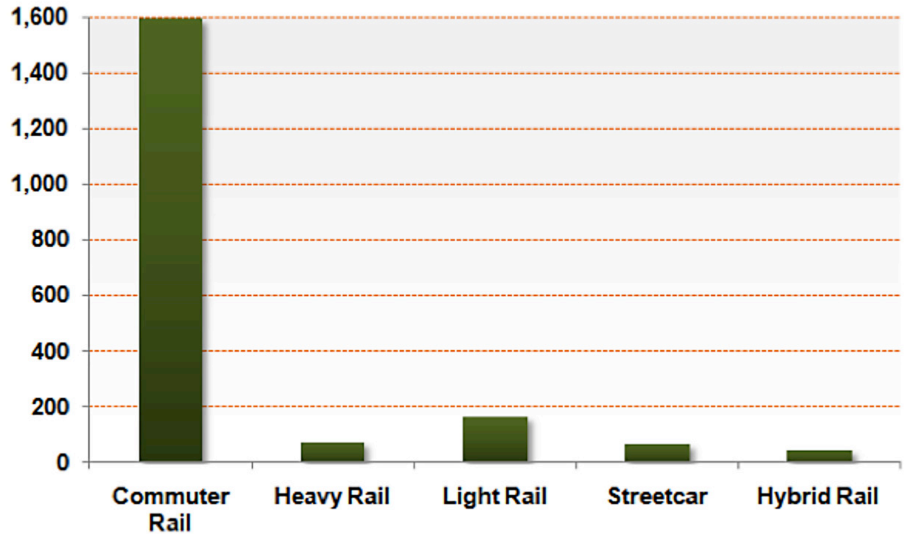
Percent of Revenue Vehicles Maintained by Contractors (2011)



Source: NTD

Figure 1-6

Total Number of Revenue Vehicles Maintained by Contractors (2011)



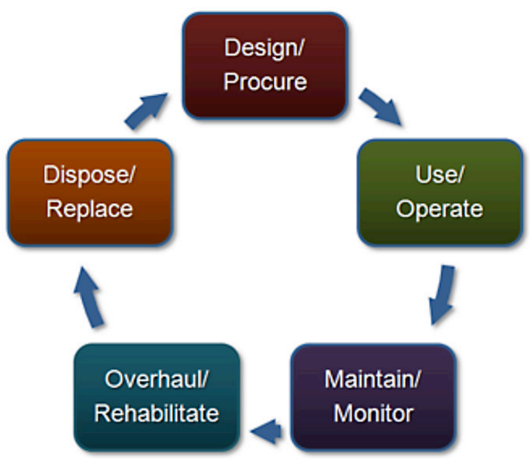
Source: NTD

Introduction to Railcar Lifecycle Management Activities

Similar to most transit assets, railcars follow a well-defined asset lifecycle. As shown in Figure 1-7, railcar lifecycle management involves oversight and coordination of the following activities: vehicle design and procurement, fleet use and operation, fleet maintenance, monitoring, rehabilitation, and overhaul, and, finally, vehicle disposal and replacement. The goal of lifecycle management is to understand and minimize the total cost of ownership of an asset while still meeting its performance requirements.

Figure 1-7

Railcar Lifecycle Management Activities

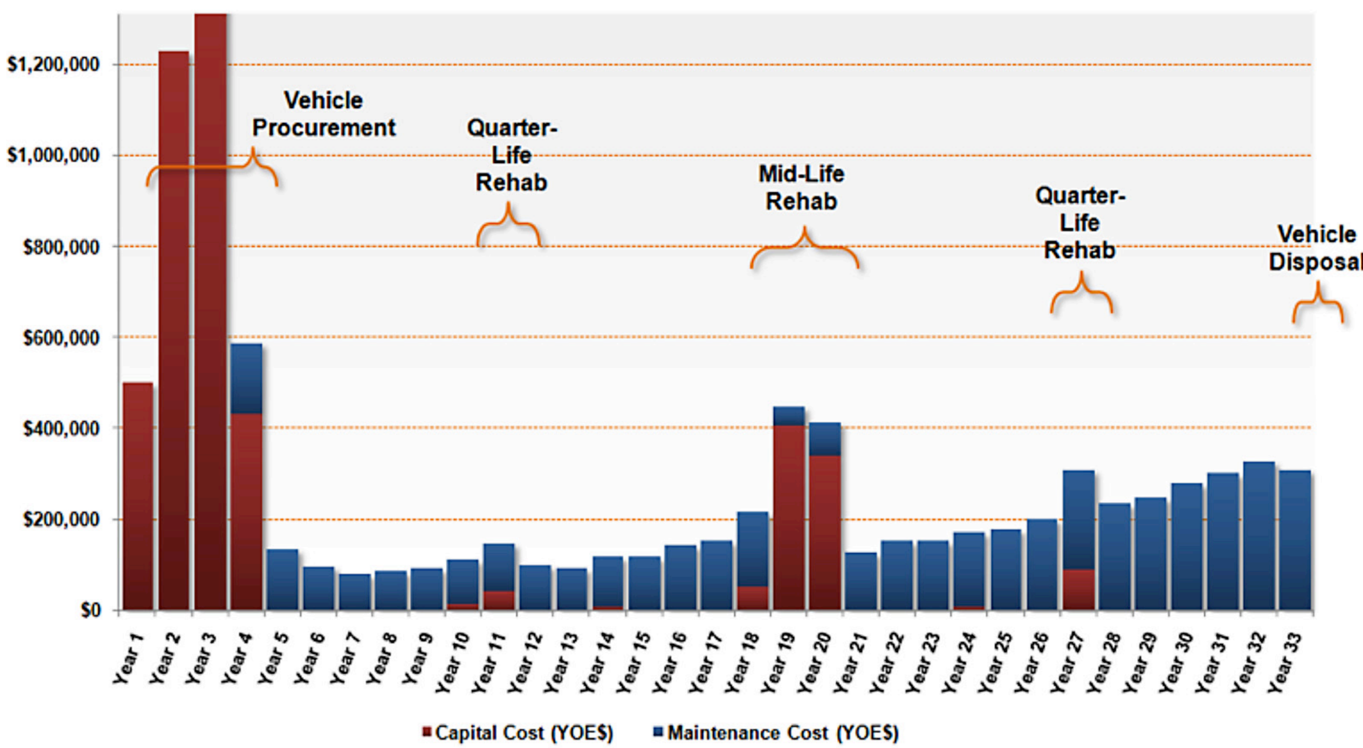


The railcar maintenance department is typically the asset "owner" for rail vehicles, meaning it oversees the rolling stock throughout its useful life. As such, railcar maintenance managers should be responsible for lifecycle costs in each phase of the railcar lifecycle, working across functions and with various stakeholders as necessary. Railcar maintenance managers are also responsible for ensuring vehicles meet their expected performance in terms of reliability, availability, condition, and safety.

Figure 1-8 provides a conceptual diagram of a rail vehicle's typical lifecycle activities and costs. While costs are most concentrated in the procurement phase, the majority of lifecycle costs, including day-to-day maintenance, rehabilitations, and capitalized maintenance, is incurred during the service life of the vehicle. The lifecycle costs are a function of the railcar's initial design and production, its ongoing reliability and maintainability, and the capabilities of the agency's fleet maintenance facilities and workforce. Furthermore, a system's unique operating environment, including its right-of-way construction, weather conditions, and intensity of passenger use, plays a significant role in determining vehicle condition and maintenance needs and therefore fleet costs.

Figure 1-8

Conceptual Diagram of Light Rail Vehicles' Lifecycle Costs



Note: This figure is based in part on cost data compiled from three U.S. light rail transit systems with similar fleets.

The following paragraphs describe each stage of the railcar lifecycle, including its implications for the maintenance department.

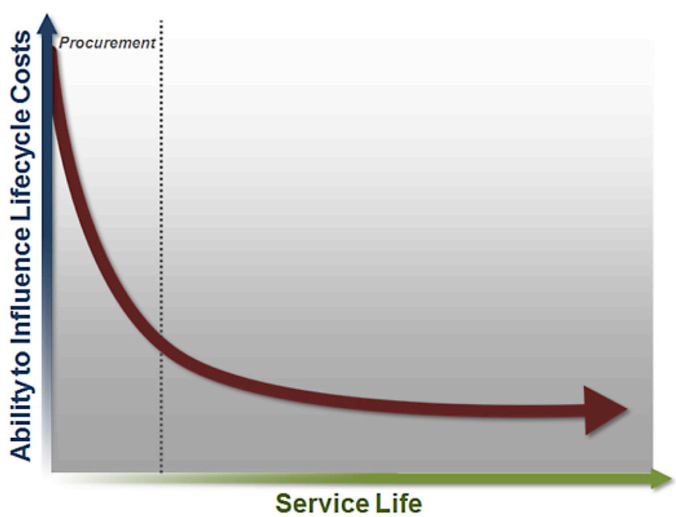
Design and Procurement: Railcar procurements are major capital programs that require identification of funding needs and sources years in advance—both because they require a significant investment and because program planning and design usually begin several years in advance of the expected vehicle delivery schedule. An agency will develop a comprehensive technical specification for the procurement that can vary in detail and specificity depending on the size of the agency and the vehicle purchase as well as the agency's particular requirements and customizations for the vehicles.

Large transit systems often replace large portions of their fleet at once, and small rail transit systems may even replace their entire fleet through a single procurement. Larger procurements benefit the transit agency because they allow economies of scale for the purchase and because having fewer vehicle models in service at any given time simplifies maintenance department operations and reduces overall costs. The lumpiness of the initial purchase often carries on to successive lifecycle phases with significant peaks in maintenance and capital costs for major rehabilitations. System and service expansion are also typically associated with large new vehicle purchases, which often also cover part of the system's fleet renewal needs.

The procurement phase of a railcar's lifecycle is a major determinant of the fleet's reliability and maintainability throughout its operational life. Therefore, a whole lifecycle approach which includes the involvement of maintenance staff in the design and procurement of railcars is critical. Figure 1-9 shows how procurement decisions, especially early in the process, have a disproportionate impact on lifecycle costs and highlights the importance of maintenance staff's close involvement in the procurement process. This report considers the role of maintenance staff in vehicle procurements and the factors to be considered in procurement to ensure the quality and maintainability of the new vehicles.

Figure 1-9

Level of Control Over Costs Through the Railcar Lifecycle



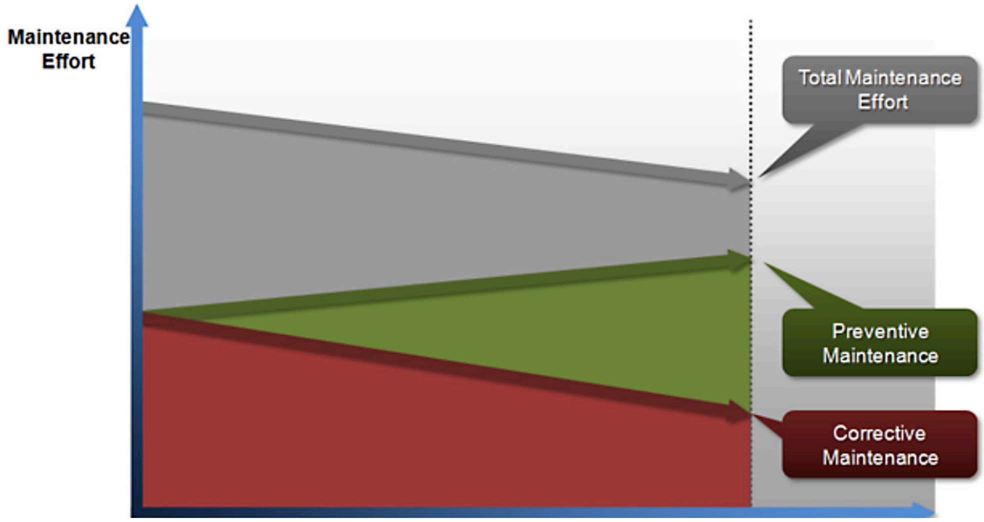
Maintenance, Monitoring, and Minor Rehabilitation and Overhaul Programs: A large portion of the railcar's lifecycle cost is focused on maintenance, monitoring, and minor rehabilitations. Once railcars are delivered, they are maintained by the transit agency or a contractor in maintenance facilities. Maintenance and minor rehabilitation activities include the following types of maintenance:

- Reactive maintenance – addresses vehicle operating failures (for example, an equipment malfunction or exogenous damage to the vehicle from weather or a traffic incident) or faults identified as part of preventive maintenance inspections. By its nature, reactive maintenance is unplanned and is a major component of the increased costs, both direct and indirect, associated with lower reliability.
- Preventive maintenance – is designed to maintain the condition and reliability of rail vehicles and systems in order to avoid in-service failures that disrupt service. Preventive maintenance is critical for managing the lifecycle costs of vehicles. Preventive maintenance includes:
    - Scheduled maintenance – preventive maintenance occurs at regular intervals of use
    - Predictive maintenance – preventive maintenance occurs based on measured vehicle system condition or performance
    - Proactive maintenance – maintenance staff works to identify and mitigate or eliminate causes of vehicle system failures prior to failures occurring
- Ongoing or "running" rehabilitation programs refer to more intensive preventive maintenance activities that are capitalized because they include a major rebuild, overhaul, or upgrade but that nevertheless can be conducted on-site by maintenance staff and allow the vehicle to remain in service.

Figure 1-10 shows how effective preventive maintenance improves reliability and reduces reactive maintenance costs. Manufacturers provide guidelines for preventive maintenance, which agencies tend to follow, and for a given railcar vehicle type, maintenance practices are broadly shared across the industry.

Figure 1-10

Impact of Effective Preventive Maintenance on Total Maintenance Effort[9]



Maintenance managers are responsible for conducting the planning, performance monitoring, and ongoing performance improvement to ensure the effectiveness of their preventive maintenance program, maximize reliability, and minimize levels of reactive maintenance. When a preventive maintenance program is ineffective, whether because of poor design or implementation or lack of resources, it can result in a downward spiral as more staff fall into a "find and fix" mentality instead of proactively addressing maintenance issues before they result in reliability issues. Various strategies and approaches for effectively managing maintenance, emphasizing preventive maintenance and maintenance quality and cost-effectiveness, are covered in Section 3.

Major Rehabilitation and Upgrade: Railcars undergo heavy use and major mechanical stress from heavy weights operating at high speeds. Even a highly effective preventive maintenance program cannot necessarily maintain the condition of all vehicle systems and elements indefinitely. As core vehicle elements, such as its body and frame, reach critical condition levels, it may be necessary to conduct a major overhaul and rehabilitation program, taking vehicles out of service to address these issues simultaneously and restore the vehicle's condition. As part of the rehabilitation program, it may also make economic sense to overhaul other vehicle systems in less critical condition because of lower costs. Rehabilitations also offer the opportunity to upgrade and replace vehicle technologies systems as necessary and make improvements for passenger comfort, safety, and satisfaction.

[9]As an example of the implementation of a successful preventive maintenance program, the Bay Area Rapid Transit District's fleet Strategic Maintenance Program increased fleet reliability nearly 70 percent between 2005 and 2013 while reducing the number of mechanics and technicians more than 12 percent and reducing fleet corrective maintenance to its lowest levels ever (6).

In general, railcars receive one major rehabilitation at least halfway through its useful life, restoring its condition and reliability to "like-new" levels. However, in some cases, a transit agency may conduct multiple overhauls over the course of a vehicle's life. These can vary in scope and magnitude. The timing and scope of midlife overhauls requires careful planning to maximize its cost-effectiveness and ensure a sufficient number of spare vehicles remain available to maintain service levels. Section2,"Vehicle Rehabilitation Programs," covers rehabilitation programs in more detail.

Disposal: Once a vehicle is no longer cost effective to maintain, no longer meets safety standards, or has become obsolete and is no longer needed for the agency's spare fleet, it is ready for disposal. Agencies usually determine disposal timing based on their need to minimize the risk of having insufficient spare capacity. Railcar disposal typically involves resale through a competitive bid or similar process to ensure compensation for the residual value of the vehicles. Retired vehicles may be used by another agency or scrapped for recycling. Through the disposal process, the agency must ensure it complies with all lease, FTA, and environmental requirements.

Benefits of Improved Railcar Maintenance Management

A high performance fleet maintenance program supports the delivery of quality, reliable service for passengers. Effective maintenance management practices can help improve rolling stock reliability, which in turns increases vehicle availability, increases the fleet's productivity, and allows the agency to operate with a lower spare vehicle ratio. A high performance maintenance program reduces overall railcar maintenance costs through better allocation of resources and more efficient and effective maintenance processes. Finally, it sustains the useful life of vehicles and reduces the long term capital costs of the fleet. Table 1-4 highlights some of the key benefits associated with improved railcar maintenance management activities.

Table 1-4

Railcar Maintenance Management Benefits

Transit Agency Business Benefits	Asset Management Approach
Improved customer service	• Reduces accident risk and improves safety • Reduces missed trips and in-service failures • Improves on-time performance and vehicle condition and cleanliness • Focuses performance and investments around customer-centered goals and metrics
Improved productivity and reduced costs	• Improves vehicle maintainability and maintenance efficiency • Improves vehicle reliability and availability and thereby reduces corrective maintenance costs • Increases fleet productivity and vehicle useful life and thereby reduces the total number of revenue vehicles needed (and associated capital costs) to provide the agency's target level of service
Optimized resource allocation	• Uses condition-based maintenance and improved diagnostics to better time and target maintenance and improve maintenance efficiency and effectiveness • Better aligns spending with an agency's goals and objectives to obtain the greatest return from limited funds • Uses maintenance planning to better allocate resources and manage lifecycle costs • Ensures alignment between maintenance needs and labor, facilities, and other resources • Incorporates lifecycle cost, risk, and performance trade-offs into procurement planning and operations and maintenance budgeting
Improved stakeholder communications	• Improves collaboration with upstream, downstream, and lateral stakeholders • Fosters more focus on internal clients and end customers • Provides stakeholders with more accurate and timely customer-centered performance indicators

The Challenges the Industry Faces with Railcar Maintenance Management

Transit agencies face significant challenges with regard to railcar maintenance management. Some challenges are related to equipment—ensuring the quality of the vehicle technology and responding to changing maintenance needs through the railcar lifecycle. These are addressed in Section 7 on new vehicle procurements and in Section 3 on reliability-centered maintenance. Some of the most critical challenges relate to the efficiency and effectiveness of the railcar maintenance organization, including managing the maintenance workforce, responding to evolving skill requirements, and adapting to new business models. These challenges are addressed in Section 3 on total productive maintenance and Section 6 on workforce management. Finally, many agencies face financial challenges and customer and policy-maker expectations for improved performance. Table 1-5 summarizes the research findings of this report—both through literature review and interviews with agency staff—as five principal challenges related to maintenance management. They represent an imperative to seek improved maintenance efficiency as well as greater value from capital investments, which the following sections of this report seek to address.

Table 1-5

Typical Transit Agency Railcar Maintenance Management Challenges

Challenge	Description
Workforce Transitions	Without succession plans in place, many transit agencies face the ongoing risk of losing critical maintenance knowledge and experience, for example, related to why certain procedures are in place, how to use maintenance management IT tools, and how to manage the inventory for critical parts.
Ongoing Technology Advancement	Each new vehicle procurement results in an evolution in technology and a corresponding change in maintenance practices. New vehicle procurements require careful planning to ensure the maintenance workforce is prepared to properly maintain the new fleet upon its arrival.
Stagnant Maintenance Practices	As fleets age and are replaced, their maintenance needs continually evolve. It is critical to have a sustained commitment to performance at all levels of the maintenance organization and have in place effective performance improvement programs to respond to new challenges as they arise and ensure the railcar maintenance department successfully fulfills its lifecycle management and fleet performance responsibilities.
Deferred Maintenance	When capital and operations and maintenance funds face growing constraints, agencies may defer fleet replacements and preventive maintenance. Deferred maintenance and investment lead to deteriorating reliability and can result in a more stressful environment focused on managing rising levels of corrective maintenance and meeting fleet availability requirements.
Business Model Changes	As budgets have become leaner, transit agencies are increasingly adopting more diverse approaches to owning, operating, and maintaining their vehicles. Rail vehicles may be owned outright and maintained in-house, or the vehicles may be leased and maintained by a third party, usually under a performance-based contract. New business models require different management skill sets and expertise to ensure their success.

Key Aspects of Improving Railcar Maintenance Management

Improving railcar maintenance management is about having in place more effective planning, information, and improvement processes to raise railcar reliability, maintainability, availability, and quality of service and reduce railcar lifecycle cost. This report emphasizes two complementary maintenance improvement frameworks for lifecycle management and maintenance implementation that have proven effective for rolling stock assets:

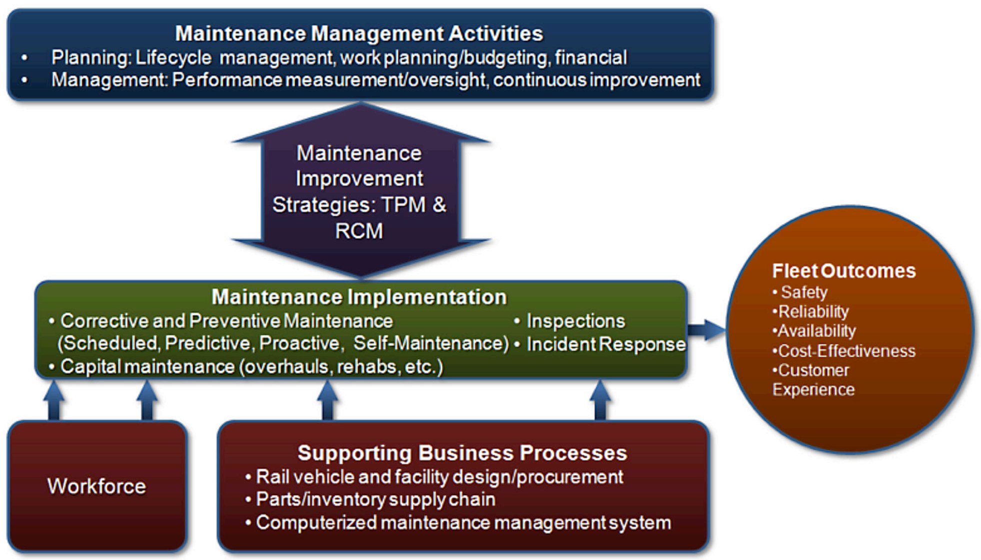
- Reliability-Centered Maintenance (RCM): a seven-step, engineering-driven process focused on equipment performance that broadly seeks to understand whether a vehicle system's design is reliable and whether its prescribed maintenance procedures are effective.
- Total Productive Maintenance (TPM): a human-focused improvement approach centered on understanding whether maintenance procedures are being performed efficiently and effectively with the goal of improving overall service quality and cost-effectiveness through continuous incremental improvements.

Each approach is easily adaptable to an agency's specific context and challenges. Together, the two approaches provide a comprehensive framework for addressing fleet performance improvement, which, even if not adopted directly, can provide important lessons for railcar maintenance departments seeking to implement effective performance improvement programs.

The remained of this report covers management practices to ensure the effectiveness of maintenance planning and performance processes. The report also addresses improvement strategies and methods focused on workforce management as well as the department's key supporting business processes, including vehicle procurement, inventory management, and information systems management. Figure 1-11 provides a framework for understanding the relationship among these various management responsibilities in the context of the department's business model. Each element of the business model is successively addressed in this report.

Figure 1-11

Railcar Maintenance Business Model



The report first addresses maintenance implementation, followed by each of the major management functions: planning and financial management, performance management, and workforce management. The report concludes with a section addressing the railcar maintenance department's role in key supporting functions: procurement, inventory management, and information technology management. Table 1-6 highlights the critical management responsibilities with respect to railcar maintenance and presents the key performance improvement opportunities presented in each section.

Table 1-6

Sections Overview

Maintenance Management Responsibility		Performance Improvement Opportunity
Section 2 – Overview of Railcar Maintenance	Select an appropriate maintenance strategy	Understand the available maintenance options and their appropriate application
Section 3 – Improvement Strategies	Have in place processes for continuous improvement	Implement Reliability Centered Maintenance (RCM) and Total Productive Maintenance (TPM) to improve maintenance efficiency and effectiveness
Section 4 – Planning Processes	Plan the Implementation of the Strategy	Use lifecycle management planning and budget and work planning processes to improve implementation of maintenance strategies
Section 5 – Performance Measurement for Fleet Management	Monitor Implementation Performance	Review and update the performance management system to better focus the maintenance organization and improve communication and decision-making
Section 6 – Workforce Training and Organizational Development	Ensure the Workforce's Effectiveness	Better select, plan, and target trainings and move toward a maintenance culture focused on customer service, quality, and continuous learning

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SECTION 2

Overview of Railcar Maintenance

This section introduces contemporary railcar maintenance management strategies in more detail, including various types of preventive maintenance. The section describes how each maintenance strategy is best applied and its role in the overall maintenance program. It also discusses alternative business models for railcar maintenance, including contracted maintenance.

The primary objectives of the railcar maintenance department are the safety, reliability, availability, and condition and comfort of the railcar fleet, with consideration for vehicle lifecycle costs. An effective maintenance approach applies an appropriate maintenance strategy or combination of strategies to each vehicle system or sub-assembly, sub-system, and component to successfully meet these objectives. This section describes the following primary considerations for the selection of maintenance strategies:

- Available maintenance strategies and their appropriate deployment
- Planning an effective major rehabilitation program
- Common fleet maintenance outsourcing approaches
- Benefits of collaboration with railcar equipment manufacturers

These four areas provide an important basis for a railcar maintenance department's implementation of its fleet maintenance program and performance improvement efforts.

The Spectrum of Maintenance Strategies

The spectrum of maintenance strategies runs from low intensity – run-to-failure and replace – to high intensity strategies focused on prevention, such as predictive maintenance. This research report identifies six principal maintenance strategies:

- No maintenance/run-to-failure: if the system or component fails, it is simply replace
- Reactive maintenance: maintenance consists only of correcting failures as they occur
- Scheduled maintenance: in addition to any reactive maintenance performed, the system or component has a prescribed set of maintenance activities performed at standard intervals

- Predictive maintenance: in addition to any reactive or scheduled maintenance performed, the system or component has a prescribed set of maintenance activities performed based on its level of use, condition, and performance
- Proactive maintenance: in addition to the standard preventive maintenance regime, maintenance staff actively seeks to address a system or component's failure causes
- Self-maintenance/design out maintenance: an engineering approach is used to remove failure causes and reduce a system's required maintenance

Table 2-1 provides further detail on each of these six principal maintenance strategies.

Table 2-1

Primary Maintenance Strategies

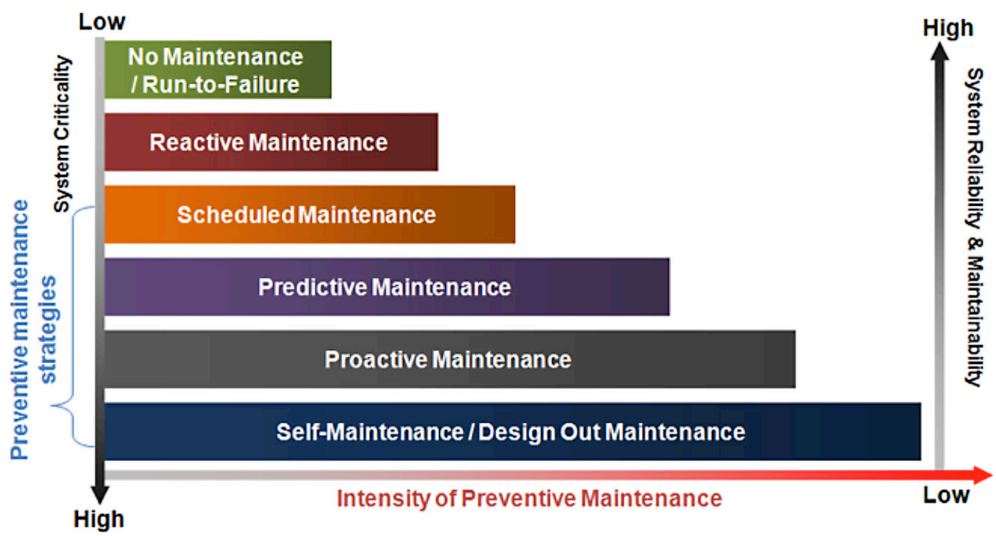
Maintenance Strategy	Description
No Maintenance/ Run-to-Failure	No cost-effective maintenance treatments exist for the asset, typically because it is either highly reliable or has a low replacement cost and low criticality relative to the cost of preventive maintenance or repair.
Reactive Maintenance	Reactive maintenance, also known as unscheduled or corrective maintenance, is conducted only in response to a fault or functional failure or an issue identified through an inspection. Typically the system is (1) relatively reliable and failures are unusual and occur apparently randomly, (2) the time and effort to repair are minimal, or (3) the system has low criticality, meaning its failure does not significantly impact overall service delivery. Preventive maintenance is not cost-effective because it has insufficient impact on the system's reliability or because monitoring and inspections are too costly.
Scheduled Maintenance	Maintenance occurs at established intervals – usually based on time, mileage, or another measure of use – that reduce the likelihood of an in-service failure. Through the examination of past failures and adoption of industry practices, the maintenance program can establish preventive maintenance practices for the timely replacement, overhaul, or remanufacture of components to reestablish their performance and reliability. Original equipment manufacturers often specify their product's recommended maintenance interval and procedures.
Predictive Maintenance	Predictive maintenance uses condition and performance data for prognostics, better timing preventive maintenance while still maintaining acceptable reliability levels. Maintenance (and sometimes inspection) schedules are based on the vehicle system's historical condition and performance data. Predictive maintenance may incur additional costs from inspection and testing of systems, as well as ongoing data analysis. In a successful predictive maintenance program, reductions in unnecessary maintenance and in-service failures should fully offset these costs.
Proactive Maintenance	This maintenance approach emphasizes ongoing improvement of maintenance processes. Proactive maintenance involves a particular focus on (1) maintenance quality and the implementation of quality assurance and quality control measures and (2) modifications to maintenance and operating procedures to mitigate conditions that lead to wear and failure. Proactive maintenance relies on many of the improvement methods supporting the Total Productive Maintenance described in Section 3. Proactive maintenance is a more intensive preventive maintenance approach and usually focuses on high criticality assets that consume maintenance resources disproportionately.
Self-Maintenance/ Design Out Maintenance	Design out maintenance is the reengineering or modification of components to improve reliability and maintainability. Self-maintenance is a related engineering approach to give systems the capability to actively manage their performance by responding to ongoing use and wear in order to better signal potential or impending faults, avoid in-service failures, maintain reliability and performance, and minimize maintenance. These strategies are most appropriate for critical vehicle systems with intolerably poor reliability or maintainability.

Source: Lee and Wang (1)

Figure 2-1 shows how the more intensive maintenance strategies are more appropriately applied to critical systems, especially those with relatively poor reliability and maintainability. Strategies toward the bottom of the graphic are considered more intensive because they typically require more data collection and analysis, more frequent intervention, more engineering support, greater use of more highly skilled maintenance workers, and closer ongoing monitoring of their effectiveness. Note that it is possible to apply any of the maintenance strategies to any indenture level[10]: the railcar, a vehicle system or subassembly, sub-system, or component (2).

Figure 2-1

Maintenance Strategy Progression



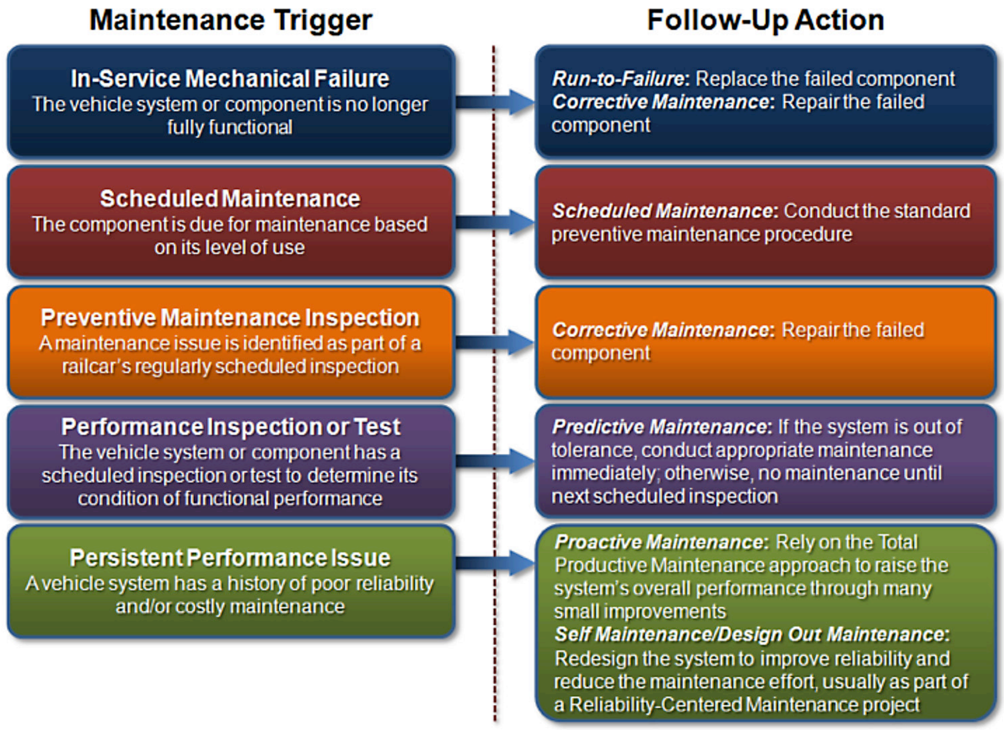
Source: Adapted from Lee and Wang (1)

All six maintenance strategies are used by transit agencies in railcar maintenance. Every railcar maintenance program commonly employs the run-to-failure, reactive maintenance, and scheduled maintenance strategies. Predictive and proactive maintenance remain emergent approaches because their implementation represents more difficult challenges. Their use can expected to spread as transit agencies increasingly have the expertise and technology to support their implementation. Railcar manufacturers have taken the lead in adding self-maintenance features to railcars and will likely continue to add such features at a steady pace through successive generations of vehicles. Figure 2-2 shows how common maintenance triggers lead to use of each of the six strategies.

[10]The indenture level of a system or component indicates where it falls in the hierarchy or organization of a complex asset, starting with the vehicle level and typically ending with the lowest replaceable unit or lowest maintainable unit.

Figure 2-2

Common Railcar Maintenance Triggers



Vehicle Rehabilitation Programs

Mid-life rehabilitation involves taking railcars out of service for the overhaul, remanufacture, or upgrade of a substantial number of vehicle systems at once. It is undertaken to restore vehicles to "like new" condition and performance and to carry out major technology upgrades. Not all transit agencies conduct mid-life rehabilitations, instead relying fully on their running rehabilitation program to maintain the fleet's condition and performance. A typical mid-life rehabilitation program includes the following objectives:

- Address systems with poor reliability
- Improve maintainability
- Restore equipment condition
- Add new features to improve safety and performance
- Address other agency initiatives (regulatory compliance, coordinated upgrade of systems, etc.)

The goal of rehabilitation programs is to manage rolling stock's overall lifecycle costs and ensure it reaches or exceeds its intended useful life.

Mid-life rehabilitations are often based on extensive input from the Reliability-Centered Maintenance approach described in Section 3 to determine the scope of the program. The project team identifies a broad set of issues to address, develops criticality scores to prioritize them, and then addresses the set of issues most likely to improve cost-effectiveness or develops a scope addressing as many of issues as possible within the project budget. In general, rehabilitations provide an opportunity to carry out "condition-based" or predictive heavy maintenance and major design-out maintenance projects. These activities are not completed during the course of normal maintenance operations because of one or more of the following factors:

- The maintenance facility lacks the equipment or capacity to carry them out.
- The activity requires special engineering and expertise to complete.
- The activity requires significant downtime for the vehicle and, therefore, is cost-effective to complete only if other overhaul activities are completely simultaneously.
- The need for the overhaul occurs rarely—only once or several times through the railcar's useful life.

MARTA's railcar rehabilitation program beginning in 2003 provides an example of the potential scope and goals of a mid-life rehabilitation program. MART's program focused explicitly on the goals of extended service life, improved customer service, and improved reliability (3). A Maryland MTA midlife rehabilitation program for its heavy rail fleet (beginning in the late 1990s) included the upgrade of microprocessors used in the automatic train control system. The upgrade improved maintainability by supporting interface with a laptop for improved diagnostics and faster repair times. In response to issues with the main convertors related to snow intrusion, the project team developed a new convertor design to improve both performance and reliability. Finally, the upgrade included a new floor material and public address system to improve passenger comfort, safety, and experience (4).

PATCO Carbody Condition and Overhaul

A major rehabilitation program can involve programmatic significant risks. The Port Authority Transit Corporation (PATCO) initiated a major railcar overhaul program beginning in the early 2000s. Inspections of the car bodies in 2002-2003—some of which were reaching 40 years old—had revealed some structural issues including cracking and areas of corrosion. The agency determined that all of the structural issues could be addressed effectively and that the overhaul remained more cost-effective relative to replacement. However, it was not until the cars were fully stripped down that the project team could verify the full extent of structural issues. Fortunately, the initial inspection program had been sufficiently thorough that, while it had not been able to map their full extent, it had successfully identified all the types of structural issues. While additional issues such as asbestos-containing material were identified as part of the full overhaul, the initial inspection process had proven an effective risk management strategy. This experience underscores the value of a initial inspection program to fully understand the issues maintenance and condition issues facing the fleet and define in detail the scope of the rehabilitation program before committing to it (10).

Rehabilitation programs face similar challenges to new vehicle procurements (see Section 7) and can benefit from many of the procurement strategies and approaches previously outlined in that section. These include:

- Extensive planning needed for successful program execution. Having in place a strong program oversight function to guide the process is critical to program success.
- Impact on vehicle availability. A successful rehabilitation program minimizes vehicle downtime. Otherwise, the agency is faced with either limiting service or maintaining a costly higher spare ratio, meaning a larger fleet with a greater overall maintenance workload and higher overall capital costs.

Many agencies are now successfully employing “running rehabilitations,” where vehicles remain in revenue service and overhauls are either designed to be completed in normal maintenance timeframes or else are completed for particular vehicle sub-assemblies off-line while a replacement sub-assembly is installed on the vehicle allowing it to continue in normal service (5), (6). If a fleet has a broad distribution of accumulated mileage among its vehicles, the agency can prioritize vehicles and run a low volume rehabilitation program – in some cases overhauling just one or two vehicles at time.

Applying Pareto Analysis to Planning Rehabilitations

Pareto analysis is a simple method for selecting a limited number of priority issues to address. The raw data, such as number failures for a given vehicle component or system, are ordered by descending magnitude (in this case, frequency). Once this is charted as a cumulative distribution, it should become clear that in most cases, a relatively small portion of the items (in this case, vehicle components) are responsible for a disproportionate share of the failures. Addressing these top "problem" systems will have the greatest impact on overall vehicle reliability (12).

Pareto analysis is an effective first step in a reliability analysis and was used to help direct engineering resources for the San Francisco Municipal Transportation Agency's first rehabilitation of its Breda light rail vehicle fleet. Maintenance planners identify the systems requiring the majority of maintenance resources because of frequent failures and high repair costs (9).

Outsourcing Railcar Maintenance

Most transit agencies find it cost-effective to use vendors for a variety of specific maintenance activities. Railcar maintenance departments commonly use two types of narrow equipment maintenance contracts:

- Ongoing warranty or service contracts with an original equipment manufacturer (OEM) for the repair of vehicle components, usually with repair off-site according to an agreed price list
- As-needed third party maintenance contracts for heavy or specialized maintenance for which the agency lacks required maintenance equipment, expertise, or capacity, usually with repair off-site on a time-and-materials or similar cost basis

Warranty or service contracts with the OEM must typically be negotiated as part of the original equipment procurement and then renewed at regular intervals. Such contracts are especially valuable to help the railcar maintenance department manage risk for high technology vehicle systems. Manufacturers are increasing taking on lifecycle management roles. Most major passenger railcar manufacturers now offer asset management services including mid-life overhauls or fleet upgrades and modernization and ongoing maintenance services, as well as asset management tools and special condition monitoring equipment like wheel profile measurement and RFID tagging for component traceability. Agencies can initiate a third-party maintenance contract at any time as fleet needs and maintenance capabilities change. For both approaches, transit agencies must carefully assess how the contract might affect vehicle repair times and availability and have effective quality control measures to ensure the contract's value. Third-party maintenance contractors can present a particular risk with respect to fluctuating prices, availability, and service quality, which can present an ongoing challenge for a transit agency's railcar maintenance managers. (Figure 2-3 details further advantages and disadvantages of contracting maintenance.)

In an alternative approach, a large proportion of transit agencies, especially smaller transit agencies and non-heavy rail systems, have opted to fully contract out their fleet maintenance function. Fully contracting fleet maintenance is a strategic decision that should be revisited within the context of periodic agency strategic planning initiatives which review at the highest level the agency's service delivery strategy. Major vehicle procurements and system expansions are also an opportunity to consider various maintenance contracting options and evaluate their lifecycle cost implications. For instance, some vehicle lease agreements leave responsibility for maintenance to the lessor, who then contracts with the manufacturer or a third party maintenance contractor. Three primary approaches exist for contracting maintenance operations and these are described in Table 2-2.

Table 2-2

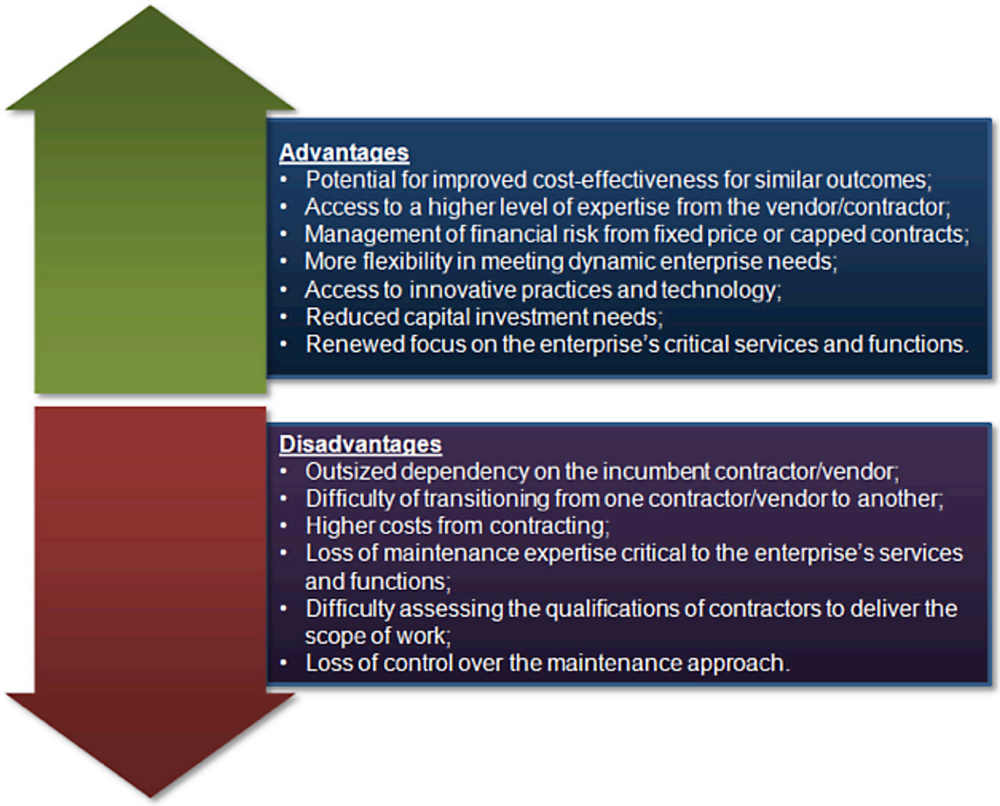
Approaches to Contracting Railcar Maintenance

Maintenance Contracting Approach	Transit Agency Role	Contractor Role	Risk Transfer
1 – Prescriptive Contract	Maintains all decision-making control, including deciding what must be maintained, when, and how	Provides the maintenance resources and is responsible for meeting a prescriptive scope of work	Agency transfers minimal risk
2 – Partial Delegation	Maintains ultimate responsibility for the asset; however, decision-making is shared with the contractor	Provides input into how, when, and what type of maintenance is conducted.	Agency transfers some risk
3 – Full Delegation	Purchases the service delivered by the asset (e.g., passenger seat-miles)	Accepts full responsibility for the asset	Agency transfers all risk

Note that compensations schemes under all three approaches may be performance-based to various degrees. Differences in compensation schemes represent different degrees of financial risk transfer as opposed to delegation of management responsibility (7). Figure 2-3 elaborates some of the key advantages and disadvantages of outsourcing railcar maintenance. Note that most of the points in Figure 2-3 apply both to fully contracted maintenance and narrow maintenance contracts.

Figure 2-3

Advantages and Disadvantages of Contracting Railcar Maintenance



Many of the disadvantages listed above increase with the specialization of the maintenance services outsourced because the agency has access to fewer qualified vendors. Transit agencies in smaller or more isolated markets often experience these disadvantages more acutely (7).

Virgin Trains' Railcar Lifecycle Management Model

As an example of the third approach, Virgin Trains contracted with a major rail manufacturer to furnish new intercity passenger trains and provide maintenance services for the company's West Coast Mail Line operations in the United Kingdom. The performance-based contract effectively passes all asset management responsibilities to the vehicle manufacturer, which has led the manufacturer to not only develop a variety of tactics to improve maintenance practices, but also to focus more on maintainability in the vehicle design stage (11).

As it took over long-term maintenance, the manufacturer has increasingly used performance-based contracts for its own suppliers. In many cases, these align with the maintenance contract, passing through contract penalties to the supplier. Such contracts are a major step away from traditional warranties. The company has explicitly embraced a best-value approach with suppliers. The manufacturer requires them to supply lifecycle costs and prove maintainability through demonstrations of standard repair times. Suppliers also have more flexibility to introduce changes post design with an eye to improving quality and value (11).

The manufacturer has implemented a program where members of the train design team complete two week rotations through one of the railcar maintenance facilities. The manufacturer assigned key maintenance staff in each of the company's five West Coast Main Line maintenance facilities to various design support groups, each based in a particular facility, dedicated to provide input and review on a specific train system, for example propulsion systems. As a result, design engineers form an ongoing relationship with both a particular design support group and a maintenance facility (11).

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Collaboration with Manufacturers

Collaboration with original equipment manufacturers (OEMs) can be a valuable strategy to keep maintenance strategies up-to-date. To the extent possible, agencies should take advantage of manufacturers' support services. Information from a manufacturer can provide documentation for maintenance procedures, electronic training materials, updates to technical issues, notifications of safety modifications, and other valuable information. The maintenance department should identify the subset of manufacturers who cover critical systems, subsystems, and components and establish a strategy for tracking information that each manufacturer releases and for collaborating with the manufacturer. By formalizing this process within the agency, there is a single point-of-contact with the manufacturer and careful documentation of information received from the manufacturer. In addition, a formal relationship and communication process between the agency and the manufacturer can encourage the manufacturer to proactively engage the agency. It can also facilitate an efficient flow of information with agreed upon expectations as to the nature of reasonable requests, appropriate level of detail and documentation, and responsiveness. One railcar maintenance program can often benefit from a manufacturer's work with their full customer base (8). Furthermore, as part of the Reliability-Centered Maintenance process, updates to preventive maintenance procedures and design out maintenance efforts may require consultation or collaboration with the OEM. The OEM's concurrence on changes can be critical to address liability issues related to safety (6).

Key Success Factors

- More intensive maintenance strategies are carefully targeted to critical systems to better manage their maintainability and reliability.
- Fleet rehabilitation programs are designed to support minimization of whole lifecycle costs.
- Major fleet rehabilitation programs have effective program oversight.
- The department has an established strategy for what maintenance activities are outsourced and regularly reviews the strategy.
- The department has processes in place to collaborate with key OEMs, especially on the ongoing update of preventive maintenance procedures.

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SECTION 3

Railcar Maintenance Improvement Strategies

This section focuses on performance improvement strategies for railcar maintenance. It addresses the identification of opportunity areas for improvement. The section introduces two major performance improvement frameworks—Reliability-Centered Maintenance and Total Productive Maintenance— together with supporting analysis and improvement methods. The section also explains how and when to use these management approaches to drive ongoing performance improvement of the railcar fleet.

A key responsibility of railcar fleet managers is to ensure that the maintenance program applies the strategies outlined in Section 2 appropriately and implements them effectively. To accomplish these objectives, this section focuses on two principal challenges:

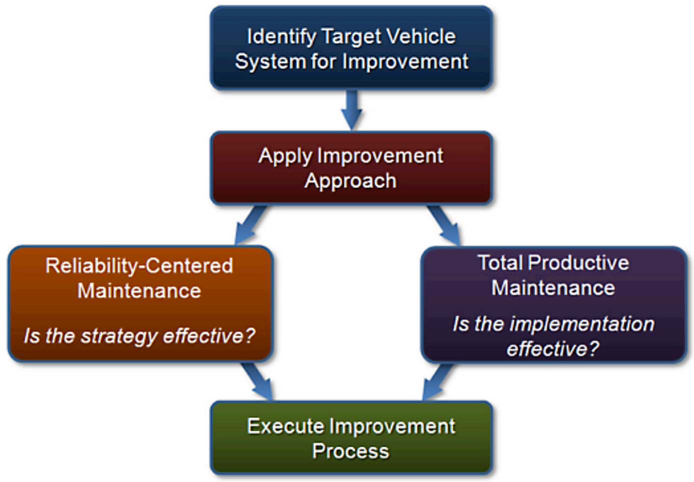
1. The railcar maintenance department must select maintenance strategies that maximize both the performance and availability of the railcar fleet within the constraints of the agency's available resources.
2. The railcar maintenance department must implement maintenance strategies effectively to realize high quality outcomes and maximum program efficiency.

Even when a railcar maintenance department is adhering to a well-established preventive maintenance program executed by an experienced maintenance staff, opportunities usually exist to improve the application of scheduled maintenance and to extend the application of predictive and proactive maintenance strategies. This section outlines how managers can focus their performance improvement efforts and resources on critical systems and issues and select and apply an appropriate maintenance improvement approach.

The two primary improvement approaches presented are Reliability-Centered Maintenance (RCM) and Total Productive Maintenance (TPM). Very generally, RCM focuses more on improving equipment reliability through the reengineering of equipment design and maintenance procedures ("Is the maintenance strategy effective?"), while TPM is principally focused on improving work quality and efficiency with an emphasis on engagement of the entire maintenance workforce in the improvement process ("Is the maintenance implementation effective?"). As such, RCM and TPM are complementary approaches. Implemented together, they constitute a comprehensive approach to fleet performance improvement and provide a helpful framework for structuring fleet performance improvement program. The overall performance improvement process is summarized in Figure 3-1. Both RCM and TPM are broadly applicable performance improvement approaches with substantial latitude for adaptation to an agency's specific purposes and can be implemented in any transit fleet maintenance program.

Figure 3-1

Maintenance Strategy Improvement Process



Identifying Target Vehicle Systems for Improvement

The first step in improving the agency's fleet maintenance strategies is to identify target areas to focus improvement efforts and resources. A "criticality analysis" can help a railcar maintenance department prioritize vehicle systems for improvement and evaluate the effectiveness of the current maintenance strategy for each vehicle system. This approach requires an evaluation of each vehicle system's (or component's) contribution to operational goals—or "business impacts"—against its maintainability and reliability. High criticality systems have some combination major business impacts, poor reliability, and poor maintainability. The criticality analysis results show which railcar systems have the greatest potential for improvement and also support the selection of an overall improvement approach.

The steps to complete a criticality analysis include:

1. Evaluate a vehicle system's or component's business impacts.
2. Establish overall maintenance effort required for the vehicle system or component.
3. Use criticality analysis to select specific vehicle systems and components for improvement.
4. Select a performance improvement approach.

These steps are described in more detail below.

Evaluating the Business Impacts of Vehicle Systems and Components

A vehicle system's (or component's) criticality is in part a reflection of its contribution to operational goals, referred to as "business impacts." For railcars, the impact of a vehicle system's failure on vehicle operation and safety is the most important factor in determining the system's business impacts. Systems whose failure can result in a service interruption have a higher criticality rating. Maintenance staff may find it useful to map key failure modes for vehicle systems and subsystems to better understand their operational impacts and help assess each asset's business impacts. As discussed in the call-out box below, functional mapping and functional block diagrams are a valuable tool to support mapping of failure modes and their business impacts.[11] A vehicle system with major impact on other key business goals—customer service, Americans with Disabilities Act (ADA) compliance, or fare collection, for example, may also receive consideration for having more crucial business impacts. The easiest way to compare assets' vehicle systems business impacts is to score every asset in each impact category (service reliability, customer service, ADA compliance, etc.) and then calculate an overall score with a simple weighted average. The overall business impact of a vehicle system is typically recorded as an attribute in the computerized maintenance management system[12] (CMMS).

[11]Functional mapping also supports other performance improvement methods discussed later in this section.

[12]The electronic work order system that tracks all maintenance work by vehicle in terms of labor, materials, work performed, etc.

Functional Mapping

Functional block diagrams are a valuable tool for modeling complex vehicle systems and can support a variety of valuable analyses, such as root cause failure analysis and criticality analysis, especially when paired with data from the CMMS. Figure 3-2 shows a high-level functional mapping of a railcar. The arrows represent interfaces between systems, where the arrow indicates a unidirectional relationship with the upstream system effecting action in the downstream system. Functional block diagrams are a way to visualize a vehicle's components, functions, and interfaces, which can in turn help understand each system or component's business impacts. A more detailed functional mapping serves as the basis for describing and understanding the most common or critical failure modes of a railcar. Ideally, the mapping occurs at the level of the lowest maintainable (or replaceable) unit (1). The first step in a functional mapping of vehicles systems is to categorize the various functions of each system. These include the following:

- Essential functions: If the system loses this functionality, the vehicle can no longer operate safely or effectively. Examples: Passenger doors, braking system, propulsion system.
- Auxiliary functions: These functions are important for normal vehicle operation, but their deterioration or failure does not necessitate immediate cessation of the vehicle's operation. However, it may be necessary to adjust the vehicle's operation parameters or desirable to remove the vehicle from service. Examples: Windshield wipers, suspension system, lighting, passenger information system.
- Protective functions: Systems with protective functions ensure safety of the vehicle, passengers, and the surrounding environment. Examples: Horn, emergency braking system.
- Information functions: Systems with information functions collect data the vehicle's operation, performance, and condition. Examples: Onboard computer system, ATC equipment, oil condition sensor, track geometry sensor.
- Interface functions: These functions cover the systems and components on the vehicle that serve to integrate the various systems, subsystems, and functions of the vehicle. Interface functions include connectors mediating physical interaction, isolators inhibiting interaction, and convertors which alter the medium of a process. Examples: Electrical and communications wiring, insulation, pneumatic system, transmission, control software.
- Superfluous functions: These functions are extraneous to the vehicle's operation and serve secondary vehicle functions. Examples: Seat cushion, fare collection equipment (8).

Functions can be either online or offline. Online functions are in continuous operation, such that failure is immediately observable and evident or detectable. Offline functions have only intermittent operation, and so their failure may be latent.

Each of the vehicle system functions described above can be defined by performance standards and tolerances that characterize normal or acceptable functioning. When the system function operates outside of these performance standards, it is considered a functional failure. Functional failures can be characterized as:

- Total loss of function: The system no longer provides the function at all and all downstream functions are fully impacted.

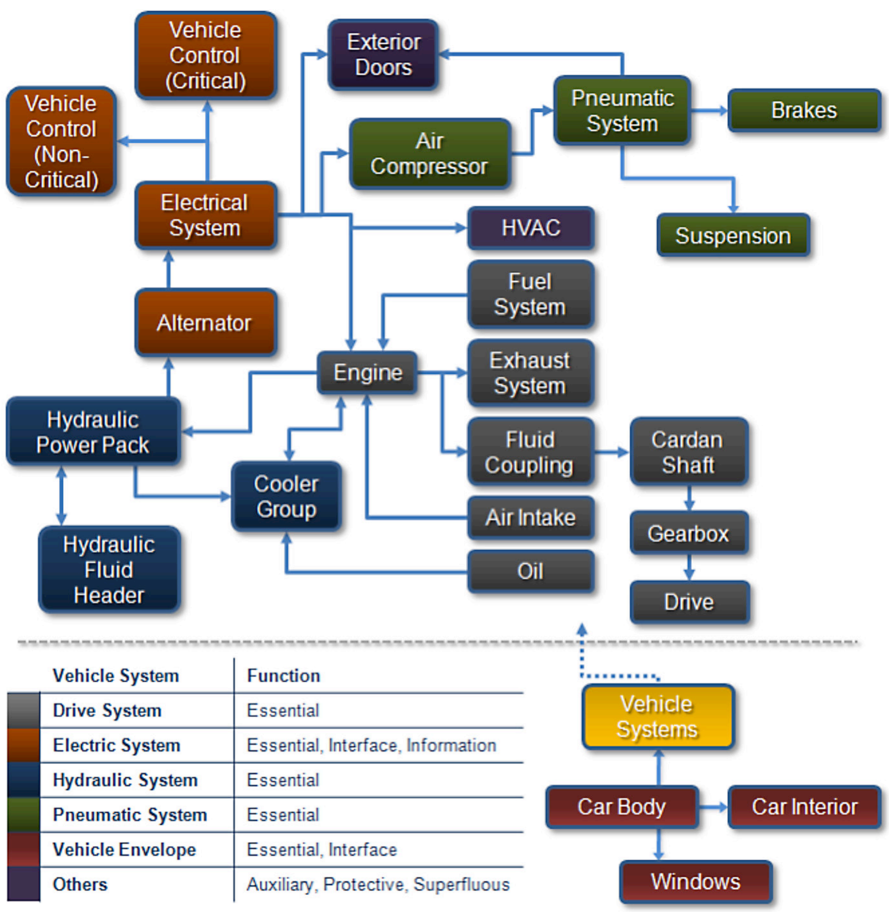
Functional Mapping (cont.)

- Partial loss of function: The vehicle system experiences a loss of quality of the function. The function can continue to operate but not at an acceptable standard. Downstream functions are not necessarily fully impacted.
- Incipient loss of function: The condition of the vehicle system is such that there is a high probability of immediate failure if no preventive or corrective action is undertaken.
- Erroneous function: The vehicle system exhibits a control logic failure and has performed the wrong function.

A careful definition of a railcar model's most common and critical functional failures provides a clear basis for determining the business impact of each vehicle element to help prioritize maintenance resources. An asset element's business impact is often recorded as an attribute in the CMMS. Tracking various functional failure types in the CMMS can support analysis of their effects, such as impact on service and average time and cost to repair. Finally, functional mapping and characterization of functional failures can also serve as a basis to check that preventive maintenance practices effectively address key failure modes. A failure mode is the root technical issue that induces the functional failure. Together with asset criticality information, such information supports the prioritization of function failures for follow-up root-cause failure analysis and Reliability-Centered Maintenance (9).

Figure 3-2

Functional Block Diagram of a Diesel Multiple Unit



Vehicle System	Function
Drive System	Essential
Electric System	Essential, Interface, Information
Hydraulic System	Essential
Pneumatic System	Essential
Vehicle Envelope	Essential, Interface
Others	Auxiliary, Protective, Superfluous

Source: Adapted from Chater (1)

Establishing Assets' Overall Maintenance Effort

While a vehicle system's business impacts are relatively fixed over time, maintenance staff can exert significant control over the system's maintainability and reliability. The maintainability of a vehicle system is a function of the time and resources necessary, on average, to carry out necessary maintenance on the vehicle system, up to and including its periodic replacement. As maintainability decreases (i.e., the system requires greater overall maintenance effort), the vehicle system requires more maintenance resources to achieve the same level of condition and performance. As a result, it becomes necessary to deploy more intensive maintenance strategies to better manage the vehicle system's maintenance costs and performance. Because vehicle systems with low maintainability can require disproportionate use of maintenance resources, maintainability is usually an important factor in determining an asset's criticality.

Two basic measures of maintainability include:

- Mean time to repair
- Mean cost to repair

Other measures related to maintainability include:

- Parts availability
- Need for special equipment
- Need for specialized labor resources

Measures of maintainability might also include the variability of a maintenance procedure's duration or the probability that the job's duration will not exceed a given threshold. Variations of this measure include a reliability threshold—the percent of jobs completed within a given timeframe—and the expected duration. A related and more general measure covers the total labor hours per job. Other useful metrics include labor hours per vehicle operating hour, per vehicle per month, and per vehicle distance (2).

Reliability determines asset performance through the frequency of failures. As reliability deteriorates, the likelihood of service failures increases as do the associated costs of failures: incident response and service restoration, decreased customer satisfaction, and increased and more variable maintenance workload. Together, reliability and maintainability measure the overall maintenance effort for a given vehicle system. Criticality analysis is a simple analysis used to understand the relative reliability and maintainability of individual vehicles and vehicle systems, subsystems, and components, together with their business impacts. The analysis provides a basis for prioritization of fleet maintenance improvement efforts and improved maintenance strategy selection.

Measuring the True Costs of Poor Reliability

The better that railcar maintenance managers can track the direct and indirect costs of in-service failures, the better positioned they are to fully understand the reliability component of vehicle maintenance costs.

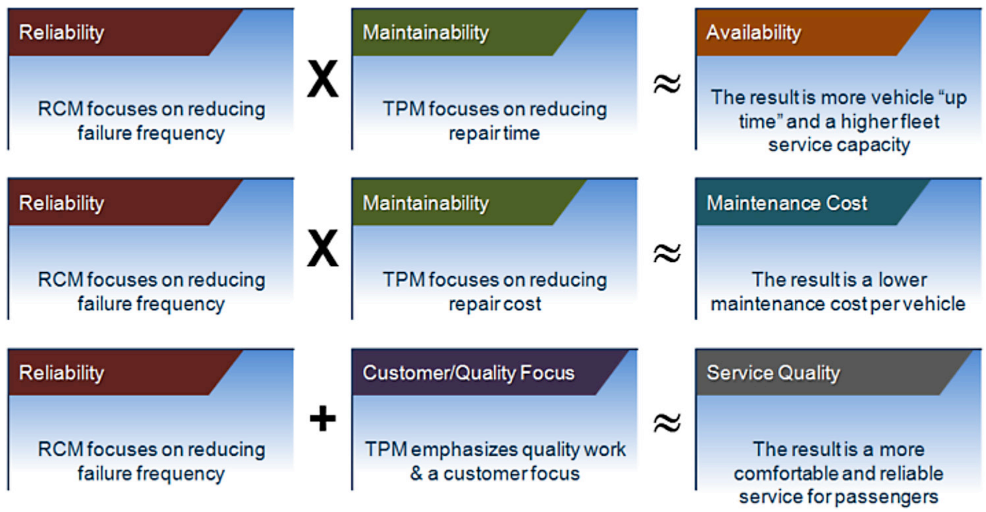
- Direct impacts include the costs of incident response and vehicle repairs (or reactive maintenance). It should be possible to track all direct costs through the CMMS. It may be possible to create a standard management report detailing direct costs by incident.
- Tracking indirect and external costs of service interruptions is more difficult but is nonetheless important since these costs can help determine of the value of measures to improve reliability.
  - One important indirect cost of service disruptions is lost fare revenue, which varies with the scale and length of the disruption, since customers do not respond immediately. Transit rail systems with electronic fare collection systems should be able to estimate these impacts from fare collection data by comparing delay incidents with normal service patterns.
  - There are also the externalized costs of delay to passengers and to other commuters. Major transit agencies may have a standard methodology in place to track passenger delay as this is an important performance measure. Total delay cost equals the total passenger delay hours multiplied by the average passenger value of time.
  - It should also be noted that improvements in reliability can also have an impact on overall ridership. While there are few estimates of the effect of reliability on overall ridership levels, even a quite small elasticity of ridership with respect to reliability could yield important increases in ridership.
- Reliability–Maintainability relationship:

$$\text{Maintainability} \times \text{Reliability} \approx \text{Overall Maintenance Effort}$$

Reliability and maintainability are crucial performance measures not only because they are controllable factors, but also because they roughly determine the overall maintenance effort required for any given vehicle system, both in terms of time and cost. Reliability and maintainability are also the two factors largely determine fleet availability. Reliability and maintainability are not only related to fleet availability, but also to maintenance cost-effectiveness and service quality, all important measures for tracking a railcar maintenance program's overall performance. Figure 3-3 illustrates the relationship between reliability and maintainability and their relationship with RCM and TPM and other high-level railcar maintenance department performance factors. The figure also emphasizes the role of RCM and TPM in improving maintenance performance. Note that RCM and TPM not only address reliability and maintainability, but also service quality through the improvement of fleet reliability, condition, and comfort (1). Together, RCM and TPM represent a comprehensive performance improvement framework, addressing all aspects of maintenance and all key performance factors. As such, these two performance improvement approaches can provide important lessons for any railcar maintenance department's performance improvement program, even if they do not adopt RCM and TPM directly.

Figure 3-3

Relationships Among Key Performance Factors



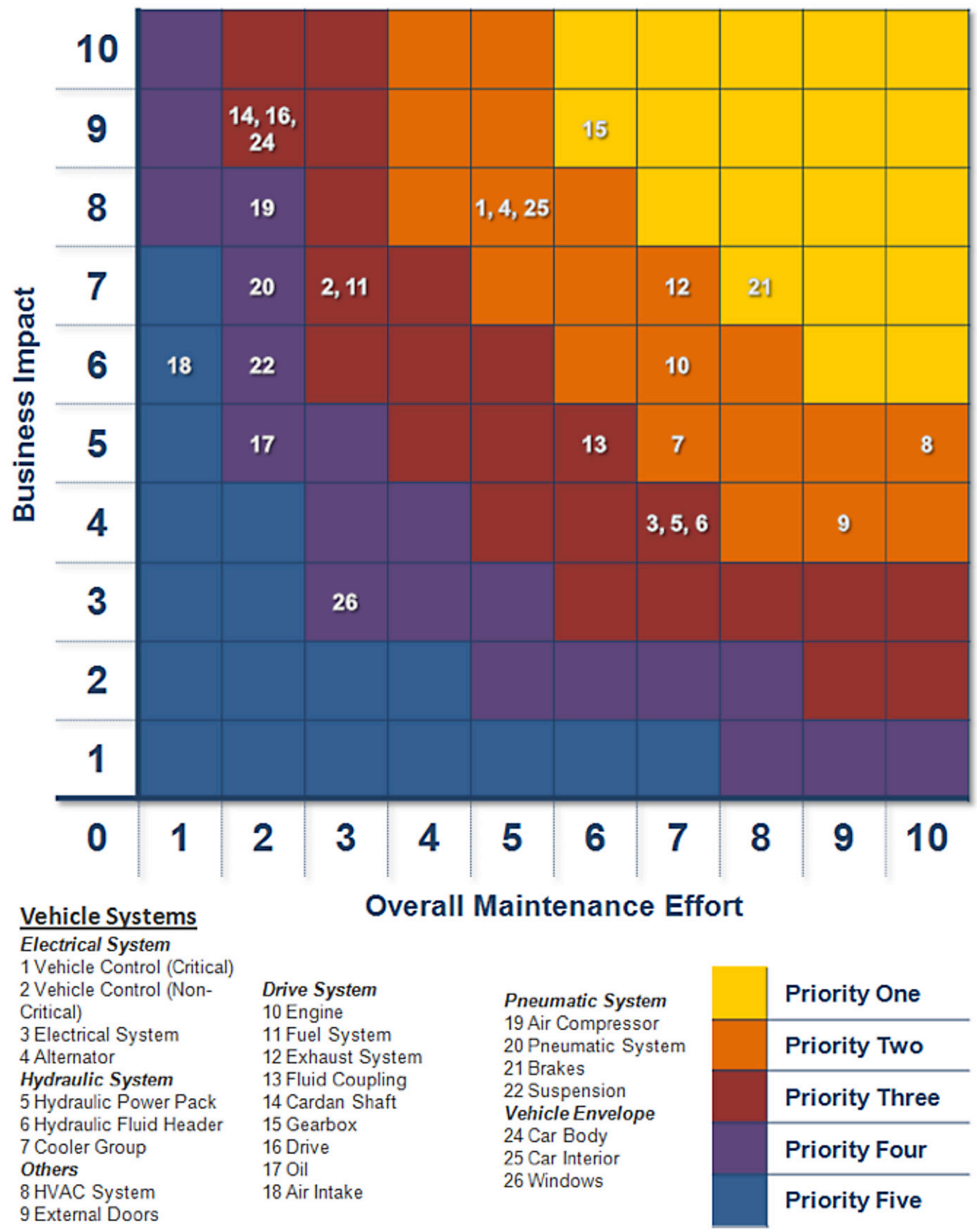
Using Criticality Analysis to Select Target Assets for Improvement

Once maintenance managers have determined each vehicle system's business impacts and overall maintenance effort, it is possible to conduct a basic criticality analysis. A criticality matrix evaluates an asset's maintainability and reliability against its business impact score. This analysis can be used as the basis for prioritizing improvement efforts and selecting an appropriate improvement strategy.

Figure 3-4 shows a criticality matrix graphing business impact against overall maintenance effort. The horizontal axis may be a measure of reliability, maintainability, or an aggregate maintenance performance measure that combines the two (e.g., the product of mean time to repair and mean distance between failures). On the vertical axis, business impact may be a weighted average of qualitative scores for safety impact, customer experience, and necessity of the system for train operation. Based on the business impact and overall maintenance effort measures, each vehicle system falls into one of five priority bands.

Figure 3-4

Example of a Criticality Matrix for Diesel Multiple Unit Vehicle Systems



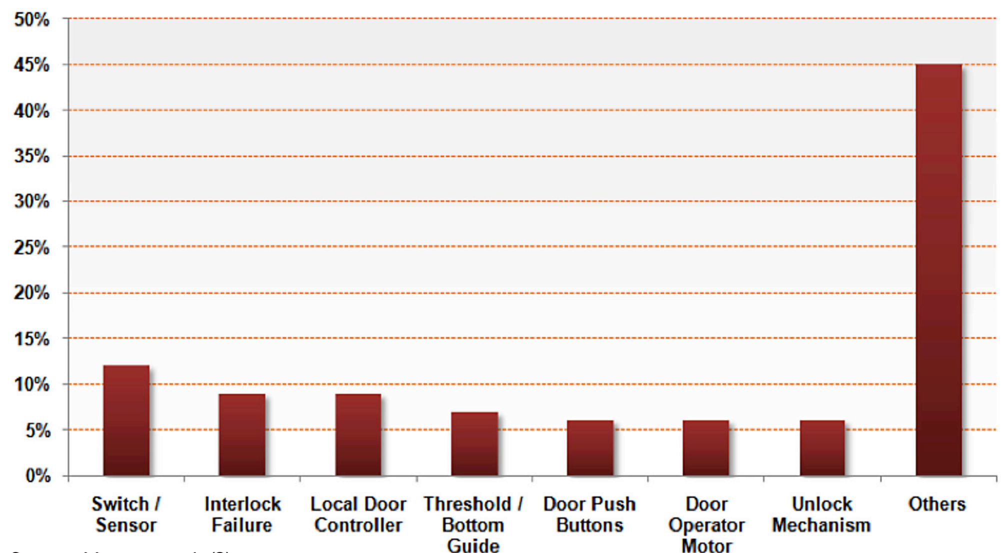
Source: Adapted from Chater (1)

All vehicle systems falling into a particular band have comparable criticality with respect to railcar maintenance operations. In general, systems in the upper-right of the matrix—in this case, priority one systems—require a more intensive maintenance strategy to better manage maintenance resources and improve maintenance performance. These assets are generally the focus of the railcar maintenance department's major performance improvement effort and resources because their improvement has the greatest impact on overall performance. Over time, the maintenance program should work to move assets on the outer envelope—those with the least favorable combination of criticality and maintenance performance—to the right. The most intensive maintenance strategies, proactive maintenance and self-maintenance/design out maintenance, are designed to drive these improvements.

Criticality analysis is also applicable to individual vehicle systems. For example, APTA's Rolling Stock Equipment Technical Forum's Train Door Project used a criticality analysis to identify the leading subsystems responsible for train door failures. The analysis showed seven subsystems were responsible for the majority (55%) of failures, as shown in Figure 3-5 (3). In the case of the APTA project, the criticality analysis was intended to identify areas for collaboration among transit agencies, including improvements of technical specifications and better outreach to manufacturers.

Figure 3-5

Share of Train Door Failures by Subsystem



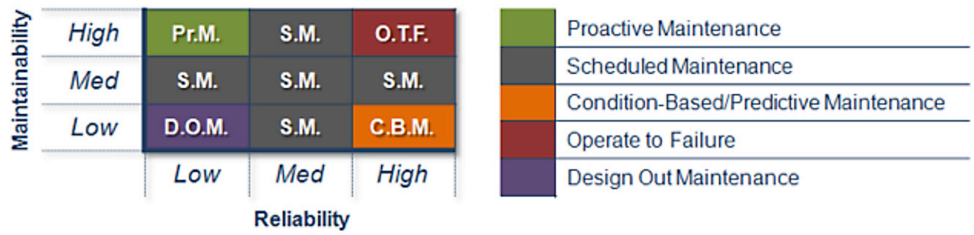
Source: Messina et al. (3)

Using a Decision-Making Grid to Better Apply RCM and TPM

A decision-making grid translates the criticality analysis results into a more specific course of action. Whereas a criticality analysis helps railcar maintenance managers select which vehicle systems to target for improvement to have the greatest overall impact on maintenance performance, a decision-making grid helps to understand what improvement approach to undertake for target assets. First, for each vehicle system, its maintainability and reliability are scored into three tiers, high medium and low, usually measured with a standard metric available through a CMMS query. Second, the reliability score is plotted against the maintainability score so that each of the assets falls into one of nine boxes on the decision grid, emphasizing a suggested maintenance strategy, as shown in Figure 3-6 (4).

Figure 3-6

Maintenance Approach Decision-Making Grid



Source: Adapted from Labib (5)

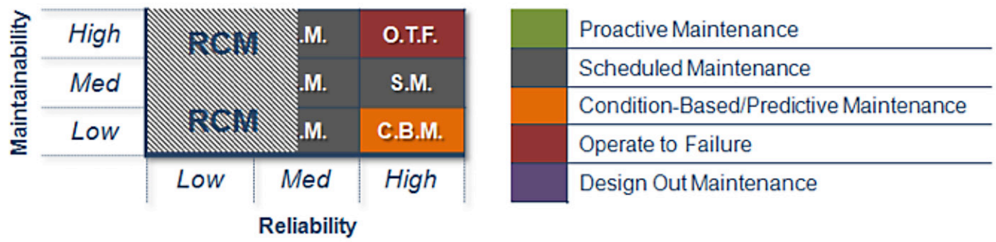
The grid provides a high-level assessment of what maintenance approach might be most appropriate to the asset. The decision-making grid can be used periodically to assess progress and reprioritize efforts. The following outlines how to interpret the results of the decision-making grid:

- Assets located in the lower left-hand corner are the worst-performing assets. The goal is to focus on the assets in the lower left and move them up and to the right over time. For these worst-performing vehicles, systems, and components, an engineering-based approach, such as design out maintenance, can help address the fundamental issues that make these assets both unreliable and difficult to maintain.
- When maintainability is low—conducting repairs and preventive maintenance is costly—and reliability is relatively high, the value of information increases, and "condition-based" or "predictive" maintenance strategies help optimize the timing of maintenance to reduce unnecessary maintenance effort without impacting reliability. On the other hand, when reliability is low and maintainability is high, the issue is often the effectiveness of maintenance. Proactive maintenance is a strategy to reduce comebacks through many small improvements in maintenance quality, such as upgrading mechanics' skills and implementing additional quality assurance measures.
- Assets located in the upper right-hand corner are assumed to be performing relatively well. Operate to failure may be an acceptable strategy. However, some level of preventive maintenance for more critical assets is likely cost-effective. Overall scheduled maintenance is the default maintenance strategy.
- When an asset is located on the left-hand side of the grid (reflecting reliability issues), the Reliability-Centered Maintenance approach is likely most effective (see Figure 3-7). RCM is described in detail in Section 3.

The specific tactics identified in the decision-making grid are covered in more detail earlier in this section.

Figure 3-7

Use RCM to Address Reliability Issues

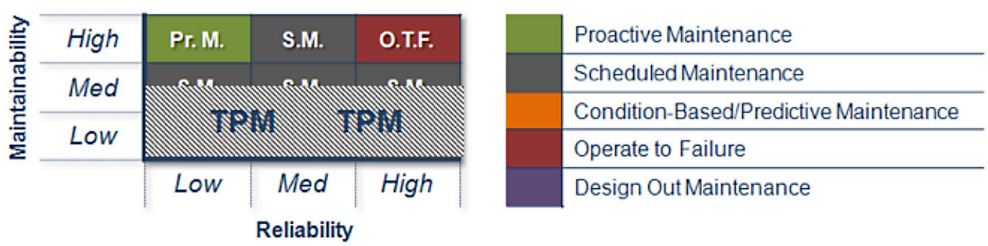


Source: Adapted from Labib (5)

- On the other hand, assets located in the bottom half of the grid (reflecting maintainability issues) may benefit from a continuous improvement approach, such as Total Productive Maintenance. As described in Section 3, TPM is designed to realize many incremental improvements in the fleet's maintainability over time (see Figure 3-8). Note that vehicle systems falling into the lower left corner of the matrix would significantly benefit from the application of RCM and TPM together.

Figure 3-8

Use TPM to Address Maintainability Issues



Source: Adapted from Labib (5)

Reliability-Centered Maintenance

Reliability-Centered Maintenance (RCM) is a maintenance performance improvement approach initially developed in the 1960s by the U.S. aviation and defense industries to create a framework for the rationalization and improvement of maintenance activities. RCM focuses on investigating and addressing failure modes identified as critical and establishing the best available maintenance treatment for repair and, especially, preventive maintenance. It is designed to improve overall railcar reliability and thereby improve financial performance in several ways: reduced frequency of repairs, improved fleet productivity through higher vehicle availability, and increased ridership through higher quality of service (6). RCM is a critical strategy for maintenance programs looking to improve their maintenance efficiency and has been successfully adopted by many transit rail and intercity passenger rail agencies throughout the U.S. and the world.

Agencies with poor reliability can realize significant consequences, including increased operations and maintenance costs and reduced ridership. Figure 3-9 shows the diverse direct and indirect consequences of poor reliability that can quickly propagate through the transit agency. As the figure suggests, the RCM process can benefit not just fleet performance but also the agency's overall performance.

Figure 3-9

Cost Implications of Poor Railcar Reliability

The primary goal of the RCM process is to reduce the likelihood of in-service failures. Other goals include improved safety, maintenance cost-effectiveness, and extension of asset useful lives. RCM helps to achieve these goals in five ways:

- Identifying failure modes that have an immediate impact on the railcar's ability to deliver service as opposed to those failure modes which are relatively less critical
- Developing or improving prognostics to better anticipate failures and perform corrective maintenance before a failure occurs
- Developing or re-engineering maintenance procedures to detect and eliminate failure causes before they happen
- Re-engineering vehicle systems or components to eliminate failure causes
- Developing or engineering measures to mitigate the impacts of a failure mode

The RCM process can also contribute to maintainability—for instance, by reducing the time for diagnostics or by improving the standardization and documentation of repair procedures (7). However, the improvement of maintainability is not usually a primary goal of RCM and is often better addressed through Total Productive Maintenance, discussed in the next section. This section describes how to plan for implementing the RCM process and then it outlines the steps and enabling factors that contribute to RCM's success.

RCM Project Teams

A successful RCM initiative depends on careful planning to ensure a focused approach with sufficient supporting staff members and expertise, adequate budget, and a defined schedule. Most of all, creating a strong team is a critical success factor for the RCM initiative. The RCM implementation and oversight teams need members both with experience in the RCM approach and with strong institutional knowledge and technical expertise. The following reflects key attributes for an RCM team:

- A new initiative usually requires effective leadership from a project champion to ensure a clear vision and support from the broader maintenance organization.
- Team members need sufficient availability to plan and implement the approach and spend time on-site with the frontline workers. At least 25 percent—or more than one day per week—availability is recommended for each team member, but team members with more critical competencies may need to dedicate significantly more time to the initiative than others. RCM implementation may require new staff—whether permanent, temporary, or contracted—to manage the additional work load.
- RCM project teams should incorporate team members with diverse perspectives. The team members typically represent key maintenance functions and skill sets, which may include project management, vehicle engineering, maintenance planning/CMMS data analysis, maintenance procedure, and quality assurance. It is critical that the team include engineers and mechanics or technicians with deep experience with the agency and its existing maintenance practices.
- Smaller project teams tend to work better—four to five members is typically an effective team size. Additional stakeholders can be included at key input and review points. A team leader oversees the team's work and facilitates planning and execution, especially coordination with functional teams affected by the project and with the rest of the maintenance department and its supporting functions like inventory management. Project team members should have clear responsibilities with respect to RCM.
- In smaller maintenance organizations that lack the same depth within their workforces, key team members, such as the team leader and the supporting engineer or analyst, may carry over between RCM projects.

However, broad participation in the process is strongly encouraged. Participation in RCM teams can help members' overall job performance by refocusing their work on core organization goals, giving them a broader perspective on their role in the organization, and providing them with new relationships and problem solving skills to deploy in their primary position.

- Having in place a cross-functional team with rotating membership helps promote information sharing and collaboration throughout the maintenance organization and helps ensure the ongoing success of the RCM program (7), (8), (9).

Once in place, the RCM team needs a clear decision making process to direct the process and respond to unforeseen issues. Team members may experience a learning curve in their new role, and, inevitably, staff may resist change and default to the "old way of doing things." A strong, transparent decision making process prevents the process from falling victim to entrenched interests and maintains the focus and momentum of implementation.

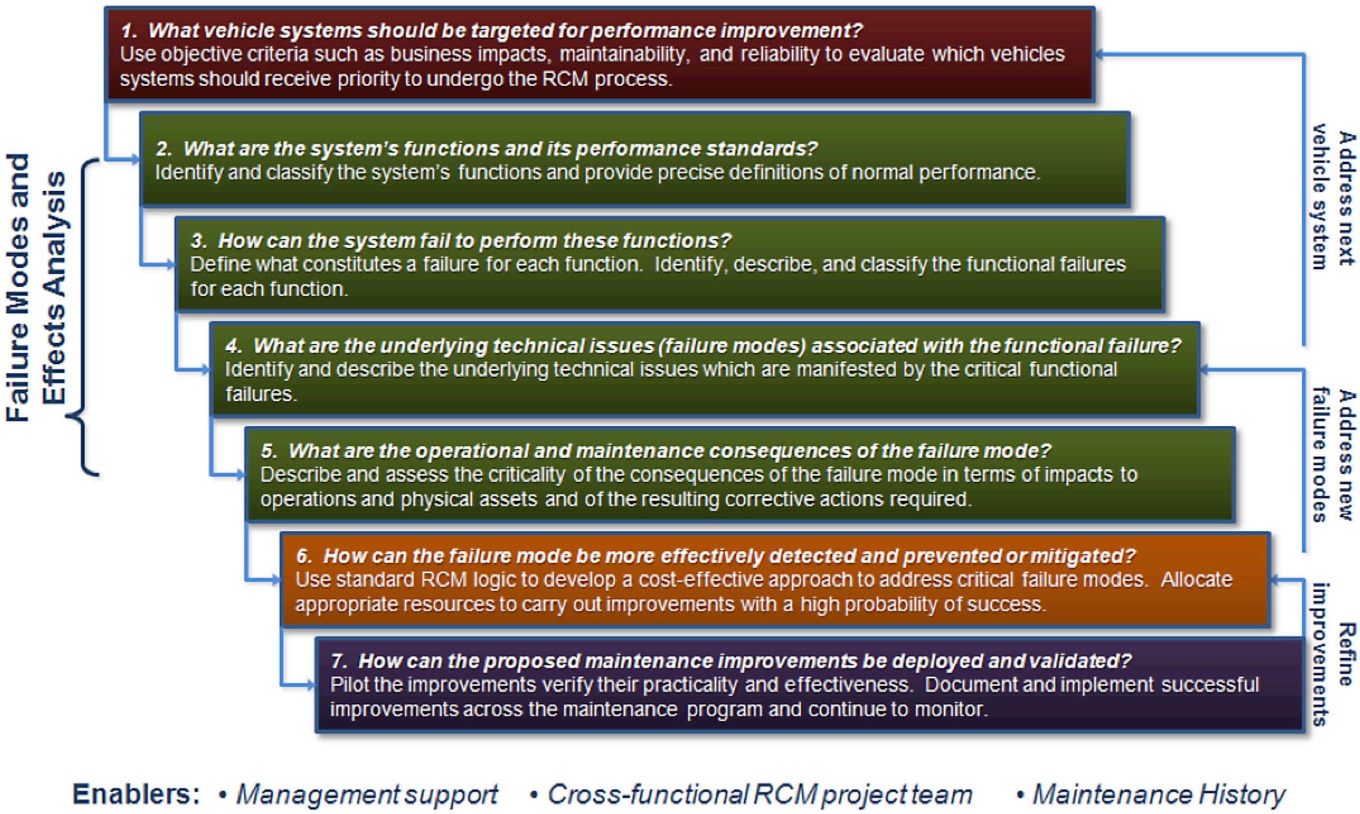
Some initial training in RCM is also often necessary to ensure a basic foundation in the process. Having a core group of committed staff with significant enthusiasm for and focus on RCM helps to motivate the whole organization and sustain the momentum required for the approach to reach maturity and success. Typically, the RCM approach is piloted in a focused area so that a subset of participants have an opportunity to learn the process, adapt it to the specific context of their organization, and work out any other issues before adopting RCM for wider use (8).

The RCM Process

Figure 3-10 lays out the seven steps of the RCM process. Step 1 identifies the scope of the RCM project. Steps 2 through 5 consist of identifying the key causes of failures through a failure modes and effects analysis. Steps 6 and 7 are dedicated to identifying and developing the optimal improvement strategy to reach the desired outcome: better vehicle reliability. Each step is described in detail through the remainder of this section.

Figure 3-10

Overview of RCM Process



Source: Adapted from multiple sources (7), (9), (10)

Step 1: Select Target Vehicle System

The first step in RCM is the determination of vehicle systems' criticality and prioritization of systems for improvement. The discussion of criticality analysis earlier in this section can be applied directly to the RCM process. Once priority assets have been selected, managers and engineers typically review the target list and provide input, such as opinions regarding where an RCM effort is most likely to succeed and the probable magnitude of potential savings. The prioritization process also depends on an agency's policies and resources. For example, WMATA goes so far as to log and investigate each service interruption; their maintenance department conducts a failure analysis when a disruption is due to mechanical failure (11).

Maintenance managers are responsible for setting a provisional project budget and timeline based on the expected benefits of the project. A focused RCM project allows the maintenance department to carefully pilot this improvement approach and adapt it to the department's needs and environment as necessary. Once the maintenance department has selected a particular vehicle system for improvement and determined RCM to be an appropriate improvement approach, the project team must be formed to implement the next steps of the RCM process.

Steps 2 through 5: Failure Modes and Effects Analysis

Once the project team is in place, the RCM process begins the implementation of the failure modes and effects analysis (FMEA), which consists of the following data collection steps:

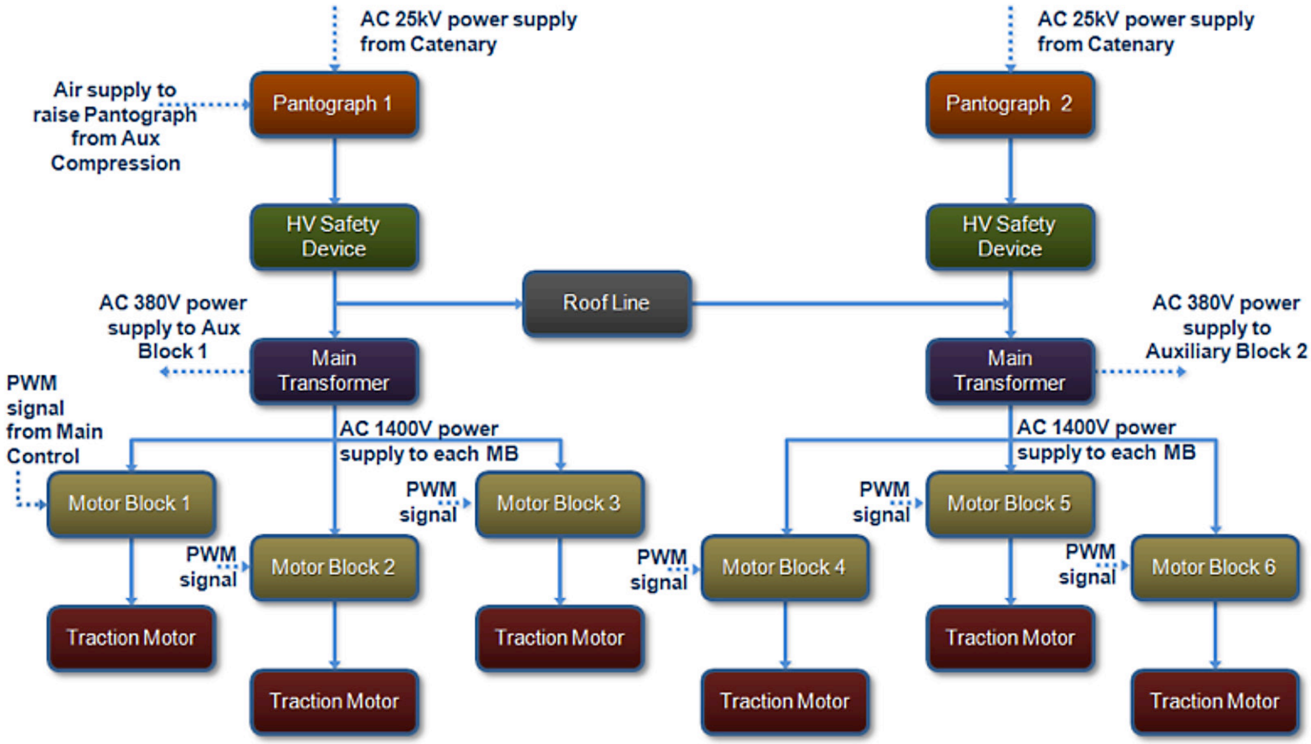
2. Define the system's functions.
3. Define its functional failures (how it failed to meet its intended function).
4. Identify the failure modes (or specific technical issue) and associated causes.
5. Identify the consequences of each failure mode.

In practice, the descriptions of the vehicle system functions and their associated functional failures are carried out in tandem. The goal is to define the system's functions and functional failures at a detailed level. The earlier description of Functional Mapping covers the general classifications of functions and failures.

It can be helpful to create a functional block diagram for the entire vehicle in order to identify higher level functional relationships between the target vehicle system or subsystem and other vehicle systems. Because of the inter-relation of vehicle systems, an RCM project may target a functional failure that impacts multiple systems. The functional mapping process must be comprehensive enough to provide the RCM team with a thorough understanding of the target vehicle system. Once a system's functional failures have been established, the RCM team can prioritize particular failures for further study and investigation of their specific failure modes. Figure 3-11 provides an example of a functional block diagram of an EMU's propulsion system, which shows the practical relationship between propulsion subs-systems and helps understand how faults upstream can propagate into failures in downstream systems.

Figure 3-11

Functional Block Diagram for an EMU Electric Traction System



Source: Adapted from Sei, et al. (12)

It is important to be detailed in the description of failure modes. The team can often identify most failure modes through a review of work orders in the agency's CMMS. Note that work orders frequently identify both failure modes and functional failures, and it is important to differentiate between the two. Also, failure data from the CMMS may not be at the appropriate level of detail. In such cases, additional data collection may be necessary; closer collaboration with front line workers may also be necessary to fully understand the issue. When a failure mode cannot be fully characterized, project team members can note these outstanding issues and investigate them later in the RCM process as the need arises.

The final step of FMEA is to describe the consequences of each failure mode. Analyzing the effects of failures helps to prioritize and focus RCM efforts. For example, an articulated streetcar with two pantographs (such as in Figure 3-11) could experience a raise/lower malfunction on one pantograph. The failure mode's effect would the effect of reducing power to the streetcar by 50 percent, resulting in reduced operating speed. However, a control system logic failure for the raise/lower function affecting both pantographs on the vehicle would have the effect of cutting all power and would strand the vehicle and interrupt service throughout the line (13). The effects of a failure fall into five main categories. These are:

- Evidence of the occurrence of the failure: this can include, among others, automatic fault detection from sensors, perception of the train operator of a functional failure, inspection by a mechanic or technician, or perception of a downstream failure mode. It is important to carefully document the expected evidence of the failure's occurrence.
- Operational impacts: the RCM team must understand the failure mode's impact on the system's and vehicle's operation not only to prioritize the failure mode but also understand the potential to manage the downstream impacts on other railcar systems and on overall railcar operation.
- Physical damage: physical damage caused by the failure mode can have implications for evidence of the failure, safety and environmental risks, and operational impacts. It can also affect the repair requirements. Addressing a failure mode can include mitigating such effects if the failure itself cannot be prevented.
- Safety or environmental risks resulting from the failure: if such risks are significant, the failure mode may receive a higher priority to be addressed. They may also have immediate operational implications, and it is important to check that they are effectively addressed by standard operating procedure.
- Correction of the failure: documentation of the repairs and any other steps needed to correct a failure provides a baseline to understand the effectiveness of current maintenance procedures, the endurance of effects from the failure. Understanding the correction of the failure also helps quantify the railcar system's maintainability for comparison with proposed improvements (6).

In practice, two failure modes of a given system can lead to the same functional failure. Figure 3-12 shows how the information collected can be organized into a simple table. The RCM team may develop this template into a more elaborate table to better document the detail of the FMEA. Note that the information in this spreadsheet can used to conduct a criticality analysis to prioritize failure modes to address. The criticality analysis follows the same basic process as detailed in Section 3. In the case of FMEA, the decision is simply whether to target a failure mode for further study by the RCM team (6), (8), (9).

Figure 3-12

Sample Table for Organizing a Failure Modes and Effects Analysis

Class of Function	Function Description	Function Failure	Failure Mode	Hidden/ Undetectable or Evident/ Detectable	Mean Interval Between Failures	Effects of Failure Modes	Current Control Measures

Source: Adapted from Marquez (6)

Data Collection for FMEA

RCM is a data-intensive performance improvement approach. Rail agencies like British Rail first adapted RCM in the 1980s when new information technology systems supporting operations began collecting higher quality performance data for maintenance, supporting FMEA (49). Likewise, New York City Transit's Scheduled Maintenance System, which followed an approach related to RCM, was made possible by advances in the agency's CMMS (59). Transit agencies should investigate opportunities to incorporate RCM functionality into the CMMS, especially as part of a CMMS upgrade or replacement. Such features include better tracking and documentation of failure modes and automated reports identifying critical maintenance issues. The collection for RCM of data beyond work histories is also important. For instance, when facing an acute maintenance issue, transit agencies often collect the damaged or malfunctioning components or subsystems for analysis by the vehicle engineering or RCM team. The RCM team may also employ special inspections and tests of a sample of systems to gather operation and condition data to better understand typical system performance parameters. Design documents from the manufacturer and prior engineering work are other important sources of information to support FMEA and may be needed for to develop the maintenance approach to address critical failure modes. In some cases, a failure mode may require collaboration with the departments responsible electrical power distribution systems, automatic train control, or track maintenance to fully understand and address the underlying failure causes.

RCM projects and other railcar engineering projects rely on detailed technical documentation. Because such complex engineering needs, product lifecycle management (PLM) is a critical information technology function for rolling stock maintenance. While the CMMS maintains data on maintenance operations, PLM covers technical documentation, including vehicle engineering. PLM functions include tracking documentation for planning, design, and manufacture or rehabilitation of vehicles, procurement, vehicle system modifications, ongoing engineering support for maintenance, maintenance procedures, technical documentation, and warranty management. PLM system functions may be integrated into a single system or spread over multiple systems. The integration of PLM functions with the CMMS/EAM provides better visibility into the use of engineering resources, better access to documentation for both RCM project teams and frontline personnel, and centralization of documentation for users. There are significant advantages to having an integrated PLM system for the entire agency, since vehicle engineering issues often overlap with ATC or track engineering issues (55).

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Step 6: Failure Detection and Prevention/Mitigation

Once the FMEA is complete, the RCM project team is prepared to address one or several failures modes. The RCM decision logic process is designed to help the team identify, develop, and implement an appropriate preventive maintenance strategy. The new preventive maintenance measure is typically designed to do one or more of the following three things:

- Provide detection and testing or monitoring for a hidden failure.
- Provide detection or prediction of an impending failure (predictive or condition-based maintenance) and better time preventive maintenance.
- Modify an existing preventive maintenance procedure or add a new preventive maintenance procedure to more effectively restore the performance and reliability of the vehicle system.

The preventive maintenance measure may accomplish these ends entirely or only partially. It is important that the RCM project team model and test that the proposed improvements to maintenance practices actually deliver the anticipated benefit. RCM decision logic provides a clear decision framework to guide the improvement process. RCM decision logic provides a process to ensure the project team remains focused and explores the most promising improvement options first before resorting to more intensive strategies. Figure 3-13 provides a succinct summary of RCM decision logic. "Yes" options in the tree represent the less intensive improvement strategy, which is typically the more cost-effective option.

Addressing Hidden Failures

As indicated in the RCM logic tree, one often successful RCM engineering strategy is to focus on hidden failures. If their latent state leads to additional potential consequences, such as downstream failures, safety issues, or other issues, then making the fault detectable can be a low-cost RCM strategy to improve maintainability and availability. The call-out box on wayside inspection technologies provides an example of the development of new sensor and detection tools to identify hidden faults or failures.

Figure 3-13

Summary of RCM Decision Logic

				Can monitoring improve the detection of the failure mode?	**Maintenance Strategy**
Yes				**1.** Can monitoring provide a sufficiently large window of action for prevention or mitigation?	
	Yes			**1.1** Define the monitoring approach including procedures, responsibilities, and scheduling.	Predictive Maintenance
	No			**1.2** Is some alternate monitoring approach available?	
		Yes		**1.2.1** Proceed to *1.*	
		No		**1.2.2** Proceed to *2.*	
No				**2.** Do data on past failures allow prediction of future failures?	
	Yes			**2.1** Are there preventive maintenance actions that can restore the system's reliability and performance?	
		Yes		**2.1.1** Define the preventive maintenance action including procedures, responsibilities, and scheduling.	Scheduled/Predictive Maintenance
		No		**2.1.2** Can replacement of the system restore reliability and performance?	
			Yes	**2.1.2.1** Define the maintenance action including procedures, responsibilities, and scheduling.	Scheduled/Predictive Maintenance
			No	**2.1.2.2** Proceed to *2.2*	
	No			**2.2** Is the failure mode undetectable?	
		Yes		**2.2.1** Is it possible to develop a test or inspection for the system to reveal a hidden fault?	
			Yes	**2.2.1.1** Define the inspection or test including procedures, responsibilities, and scheduling if applicable and proceed to *1.*	Predictive Maintenance
			No	**2.2.1.2** Is it possible to engineer a function revealing the failure mode?	
			Yes	**2.2.1.2.1** Engineer the failure mode detection and proceed to *1.*	
			No	**2.2.1.2.2** Proceed to *2.2.2*	
		No		**2.2.2** Does the failure mode have a critical operational or maintenance impact?	
			Yes	**2.2.2.1** Design out maintenance: redesign the vehicle system to eliminate the failure mode.	Design Out Maintenance / Self-Maintenance
			No	**2.2.2.2** Is it more cost-effective to redesign the system versus operation "as is"?	
			Yes	**2.2.2.2.1** Design out maintenance: redesign the vehicle system to eliminate the failure mode.	Design Out Maintenance / Self-Maintenance
			No	**2.2.2.2.2** Run to failure	No Maintenance/Run to Failure

Source: Adapted from Barry (7)

Wayside Inspection Technologies

Wayside data collection technologies may offer significant benefits to timing and targeting maintenance in large fleet agencies. Wheel impact detectors, truck performance detectors, acoustic bearing detectors, and wheel profile detectors can gather data not available from onboard sensors and relay it to maintenance staff in real-time in support of both reactive and predictive maintenance. Typically, RFID identification tags on the train identify which bogie is being measured. The data can be used to identify trucks which are not performing to standard and are causing disproportionate track wear and pose a higher risk for in-service failure and derailment. Essentially, the wayside detectors reveal otherwise hidden functional failures (48). Because railcars may pass an inspection point multiple times each day, the detector can collect information on each truck at a relatively high rate and improve accuracy through multiple measurements. If a truck consistently displays out of tolerance measurements, it is flagged for inspection. Automatic wayside detectors can also serve to evaluate the efficacy of repairs by providing “before and after” data to ensure maintenance effectiveness (51).

Metro-North Railroad installed such a system and used it to proactively identify wheel faults. The system helped reduce the average wheel dynamic to static load ratio from 2.5 to 1.8, resulting in slower track wear and savings to both vehicle and track maintenance costs (56). WMATA conducted a test of a wayside truck performance detector, measuring vertical and lateral forces to identify trucks that do not perform well in curves. The project team used a simulation tool to predict out of tolerance measurements and verified these measurements with empirical data collected from the detector. The detector effectively identifies bogies in need of corrective maintenance, such as suspension repair or wheel truing, and has been used to test the railcar manufacturer’s adherence to steering requirements on new vehicles as part of the reception process (51).

Predictive Maintenance

The RCM logic tree also shows RCM’s emphasis on predictive or condition-based maintenance. A central principle of RCM is that inspection and testing data can help model failure rates to better time and target both scheduled and preventive maintenance. Whether a reliability model is simple or sophisticated, the basic premise is to compare current measures of the railcar system’s performance or condition with historical failure data to understand the system’s prognosis—its current likelihood of failure—and to decide the most appropriate maintenance action. The RCM team must develop this understanding into a straightforward preventive maintenance procedure for frontline workers with a clear inspection protocol, entry of inspection results into the CMMS, and clear logic to determine the next maintenance steps. The inspection data recorded in the CMMS can be used to review and update the underlying reliability model.

Reliability Models

Reliability analyses may use three basic approaches to forecast system performance:

- Model-based: Actual condition and performance is compared against the performance predicted by a quantitative model of the decay process. The model focuses on understanding the causes of the decay process. The model-based approach relies on deep understanding of the mechanics driving the failure process. Model-based reliability analysis is often applied to electrical systems or to support reengineering and design modifications.
- Data-driven: Empirical data is used to establish reliability models with reliance on the foundational mechanics of wear and failure. The data-driven approach emphasizes outcomes or symptoms of declining performance to construct a statistical model of decay or failure. Such empirical modeling may use sophisticated statistical approaches such as neural networks or machine learning or simple, unfitted historical experimental failure data to establish in and out of tolerance inspection or testing results and associated empirical failure probabilities.
- Hybrid approach: a quantitative model is specified based on foundational principals and estimated using empirical data.

Such models are used for prognostics to optimize the timing of maintenance. In practice, the hybrid and data-driven approaches to reliability analysis are most common (54), (53).

Condition-based maintenance models provide conditional decay curves that may rely only on the current condition of the asset or on both the level of use (e.g., total hours in service) and the current condition together. The output of such a reliability model is a combined inspection and replacement policy based on the current asset condition. Such probabilistic analysis usually relies on empirical curves rather than a specified model like the Weibull distribution. A basic Weibull-distributed failure model is most appropriately applied to components that fail based on the hours, miles in service, or other use-based variables and therefore candidates for a scheduled maintenance strategy. On the other hand, condition-based maintenance requires simultaneous consideration of both the current condition and level of use experienced. The analyst groups condition ranges by probability of failure over several useful time horizons, for instance the intervals between various kinds of inspections (15,000, 30,000, and 45,000 miles inspections). A particular condition corresponds to an empirical reliability level and an associated maintenance action: (1) immediate preventive maintenance, (2) preventive maintenance scheduled for a future inspection interval, or (3) inspection scheduled for a future inspection interval (58).

Failure trends and decay curves are useful for the selection of an appropriate maintenance strategy for a particular component or vehicle system.

- Worst old: accelerating decrease in reliability past a certain level of use. Either scheduled or predictive maintenance can be effective. More frequent inspections may be necessary past a certain age/use level.

- Bathtub: the system's failure probability is highest at the beginning of the asset's life and near the end. Special early life maintenance, inspection, testing may be necessary. Problems are often associated with production/procurement. After the introduction phase, maintenance tactics are the same as for Worst Old.

Reliability Models (cont.)

- Slow aging: The system's reliability deteriorates constantly with age. The system usually needs a periodic rebuild or rehabilitation to restore condition. Preventive maintenance generally only slows the rate of decline. Rehabilitations are timed based on inspection/observed condition.
- Best new: The system's reliability deteriorates fastest during the initial phase of its life. Reliability is generally not age-based after the initial phase, so scheduled maintenance is not very effective. Usually run-to-failure assets depending on cost and maintainability.
- Constant: Reliability remains constant across the lifecycle. Like Best New, preventive maintenance is generally ineffective. Failure is more or less random.
- Worst new: Like Bathtub, there is a period of lower reliability initially, followed by system stability, where run-to-failure is an appropriate maintenance tactic (33).

Another challenge in instituting predictive maintenance is that it is sometimes difficult to measure a vehicle system's or component's condition and potential for failure directly. Engineers must instead use the data from existing sensors that monitor associated components or functions, or they can conduct inspections or tests of the system's visible functions and parts. Such data may then be correlated with failure modes and used for prediction. Data mining is emerging as an approach to better leverage collection and use of sensor data to support predictive maintenance and intelligent asset management systems. For example, operating data records can be linked to signature patterns indicating a critical threshold or event.

For high criticality assets, the value of condition information is much higher. With railcars increasingly capable of communicating operating data continuously over secure wireless networks, it is possible to monitor vehicles in real-time. Active monitoring of critical systems such as propulsion, doors, or the pantograph allows the operation control center to adjust vehicle operation in response to a failure or impending failure, to direct vehicles for timely maintenance, and to prevent in-service failures which are costly both to passengers and the agency (14). For instance, vibration sensors can support detection of key failure modes for gearboxes, and stress wave analysis can detect minor wheel flats that require maintenance (1). Engineers have successfully installed vibration and acceleration sensors in existing railcars to develop on-line condition monitoring of suspension systems with the ability to distinguish key failure modes. Addressing suspension issues more quickly reduces track maintenance costs, and improves safety by reducing the likelihood of derailments, and improves customer comfort (15), (16). Most railcar manufacturers already include electronic diagnostics covering most critical railcar systems. While such systems are not fail-proof and help improve overall reliability substantially, they can require maintenance and repair. Mechanics need sufficient electronic knowledge to understand and repair these systems. They also need the computer skills to operate the laptop or handheld computers necessary to download diagnostics equipment (17).

Condition-Based Replacement of Shock Absorbers

One example of condition-based maintenance is the testing of components before their replacement. The Chicago Transit Authority (CTA) developed an effective bench test for heavy rail shock absorbers. Heavy and light rail vehicles have shock absorbers usually built by foreign suppliers that are extremely durable and typically have a useful life between 20 to 30 years. CTA had previously replaced this expensive component during the quarter life overhaul of railcar trucks, based on OEM guidelines. However, these shock absorbers were never tested to determine their performance and potential for reuse.

Seeing an opportunity for cost-savings through reuse of a costly component, CTA developed a method to evaluate the condition of its shock absorbers, borrowed from a practice used by professional auto racers. Racers test their shock absorbers using special dynamometers to measure damping force so that they can meet the requirements of each track where they race. CTA found a vendor that carried a linear dynamometer that would help the agency test its shock absorbers. The vendor tested six of CTA's used shock absorbers and several new shock absorbers with a dynamometer, comparing the damping rates of the two. The test found that all six of the used shocks were still within the damping specifications for the new shocks and could safely be reused until the next quarter-life overhaul. As a result, CTA acquired its own linear dynamometer to conduct bench testing of the shock absorbers on-site and was able to put the shock absorbers back into service, saving up to $2,000 per truck. The agency normally replaces 1,200 shock absorbers a year, costing almost $500,000. However, since purchasing the shock dynamometer, CTA has achieved a 90 percent reuse rate on shock absorbers (45).

For critical vehicle systems with low failure rates, such as the car body, qualitative condition assessments offer a more low-technology option for predictive maintenance. The maintenance program sets a baseline policy to repair assets once they reach a threshold on the qualitative scale. Over time, the maintenance staff can validate and improve both the maintenance policy and the condition rating procedure based on historical data from the CMMS. Bay Area Rapid Transit District tracks fleet cleanliness through its quarterly customer survey using a qualitative scale of 1 ("poor") to 4 ("excellent"). The performance measure has helped draw attention to the issue and supported the decision to upgrade car interiors to both make cleaning easier and to better meet passenger expectations about a clean environment. The fleet maintenance program has also dedicated increased resources to clean car interiors (18), (19).

Scheduled Maintenance

In many cases, a vehicle system or component has a well-established failure behavior where condition monitoring would not substantially change the timing of maintenance. When condition monitoring cannot improve maintenance decisions, predictive maintenance has less value and scheduled maintenance is sufficient. Even in such a case, failure data are still important to optimize the fixed maintenance interval. In practice however, optimizing preventive maintenance schedules and inspections based on empirical data and reliability models can present significant difficulties. For example, a rail agency's internal audit noted that the agency was not meeting its goals of oil changes for light rail vehicles every 30,000 miles. The interval was considered conservative and was used mostly as a benchmark. Changing the requirement to the next scheduled longest interval, 60,000 miles, however, would make the preventive maintenance schedule for oil changes too long. A 45,000 mile interval just for oil changes was not practical because it did not coincide with the normal preventive maintenance schedule. The anecdote highlights the difficulty of balancing vehicle needs with maintenance capacity and the need to carefully package preventive maintenance tasks to ensure adherence to goals and performance (20).

One strategy to address this challenge is opportunistic maintenance: the practice of packaging condition-based maintenance tasks together for completion. Under opportunistic maintenance, skilled maintenance planners use maintenance interval and condition information, staff requirements, and task relationships (e.g., replacement of wheels allows access to the suspension system) to create the ongoing railcar maintenance schedule. Optimization techniques can help to both create specific schedules and general scheduling rules to address the challenges of coordinating condition-based maintenance of railcars (21). Maintenance planners use similar techniques to determine what work items to include in a major overhaul such as a quarter-life, mid-life, or other rehabilitation that takes a railcar out of service for a significant period (for more on rehabilitation programs, see Section 2, "Vehicle Rehabilitation Programs").

Design Out Maintenance

For problems that cannot be remedied through either predictive maintenance or scheduled maintenance, it may be necessary to redesign the equipment, especially in the case of safety issues. Design out of maintenance is typically a costly preventive maintenance option since it can require significant engineering resources followed either by maintenance staff conducting often costly modifications or by procurement of a replacement system or component. Design out maintenance efforts are typically targeted at vehicle systems with the most acute maintenance issues where there is a clear business case (7).

Self Maintenance

Self-maintenance or “e-maintenance” functionalities are intended to improve the maintainability of an asset and reduce the need for intensive maintenance. The idea behind self-maintenance is that a system has the capability to respond to ongoing use and wear in order to maintain reliability and performance and minimize maintenance. Individual railcar systems increasingly incorporate self-maintenance features to expand their tolerance levels, self-rectify after faults, and “auto tune” their operation under dynamic conditions (54). As an example, electronic sensors control brake and clutch action. As pads and discs wear, the electronic control compensates until the components reach a critical thickness. At that point, the electronic sensor signals a fault code which the vehicle’s onboard system communicates to the operator and/or mechanic (17). Self-maintenance functionalities include:

- Monitoring capability: real-time, sensor-based monitoring of performance and condition.
- Fault judging capability: real-time assessment of whether the system is operating within normal parameters and performance.
- Diagnostics capability: the system has the ability to identify common and likely causes of abnormal performance.
- Repair planning capability: the CMMS can use onboard systems data to identify likely repair actions and provisionally schedule them.
- Adaptive control: the system has the ability to adjust operation to avoid impending failure and maintain at least some level of performance.
- Self-learning and improvement: the system can use past data to update its control logic and further improve reliability and performance (54).

Self-maintenance encompasses “smart assets” and “intelligent” information systems that support decision analysis and automatic decision making. An example of an “intelligent” maintenance feature is the automatic update of inspection schedules in the CMMS based on past inspection outcomes and automatically uploaded vehicle diagnostics data. A “smart asset” feature would be for a system to adjust its operation when it recognizes its typical operation could lead to an in-service failure. For example, an air-conditioning unit might reduce output level after experiencing excessive loading and out-of-tolerance temperatures to forestall a failure event (54). Real-time condition monitoring is another emerging self-maintenance feature. Common sensors supporting real-time condition monitoring cover vibration, temperature, motion, acoustic emissions, ultrasonic characteristics, oil and lubricant condition, electrical performance, and physical load and stress. These are increasingly being deployed to monitor a variety of railcar systems (9).

For transit agencies to take more advantage of self-maintenance capabilities, railcar manufacturers will need to continue to expand both data collection from and control capabilities for onboard systems. Better interface with the onboard computer system improves data collection from existing onboard sensors for maintenance engineers’ use. Many onboard systems simply communicate status and fault information to the onboard computer. A system’s sensor may be measuring more complex data that can be useful for root cause failure analysis (53). Virgin Trains, a British train operator, has worked with its operations contractor, a major train manufacturer, to implement a system where maintenance personnel can remotely monitor the train’s performance while it is in service. When the onboard computer system identifies a mechanical issue, the staff at the maintenance depot can prepare for the repair in advance and minimize the train’s downtime (47). As part of procurement requirements, transit agencies may wish to push self-maintenance features and to specify maximal interface capability with system sensors to enable collection of such data or carry through of the base data to the onboard computer.

RCM at Amtrak

In 2005, Amtrak's Office of Inspector General issued a report estimating that the passenger railroad could save up to $100 million per year by adopting Reliability-Centered Maintenance throughout its maintenance organization. In response, In July 2006, Amtrak established predictive maintenance as an overall goal for the fleet maintenance organization, and moved to implement a RCM pilot program for its Acela trains used in the Northeast Corridor where passenger growth was running into fleet capacity constraints.

Through the RCM process, Amtrak reviewed and updated its three preventive maintenance cycles, conducting maintenance effectiveness reviews and root cause failure analysis (of which FMEA is a variant), and establishing a comprehensive condition-monitoring program. The railroad drew on cross-functional stakeholders to complete the maintenance effectiveness reviews, involving mechanics, operations staff, equipment engineers, equipment manufacturers, consultants, and facilitators. The RCM program targeted systems based on safety, repair cost, and operational impact and an overall risk assessment. The RCM program stressed the definition and implementation of condition inspections for critical vehicles systems, the setting of component age limits at which their replacement was mandatory, and the finding and correction of hidden functional failures before they could result in in-service failures:

- Amtrak implemented remote condition monitoring of its locomotives to allow live monitoring by its engineering staff.
- The root cause failure analysis lead to numerous component redesigns, such as the installation of a new constant displacement pump and unloading circuit for the hydraulic system supporting the train's tilt system. Within a year, RCM efforts targeting the tilt system had reduced monthly delay minutes by more than two thirds.
- One example of checking for hidden failures was the institution of a seasonal test of onboard HVAC systems, checking for refrigerant levels in condensers as an early indication of mechanical issues.
- To improve maintainability, Amtrak's RCM teams worked to better package maintenance and overhaul tasks into four hour increments, which could be performed opportunistically during the daily standard servicing and inspection window. As a result, fewer train sets need to be removed from service for preventive maintenance, while preventive maintenance tasks are still completed on schedule.

As a result of the program, Amtrak's train availability in the Northeast Corridor improved from 14 train sets to 16 train sets by 2008, permitting additional revenue runs and generating tens of millions of dollars in additional fare revenue and improving the agency's overall financial performance. In less than a year, the Acela service went from eight train annulments per month to three annulments per month (46), (52), (63), (61)

Step 7: Implementation

The final step of the RCM process is the implementation of the proposed improvements. Implementation typically involves the following success factors:

1. A clear definition of success for the project
2. Validation of the proposed improvement (usually through at least a month-long pilot, though it depends on the historical failure interval of the target vehicle system or component)
3. Full deployment of the improvement after successful pilots
4. Update of documentation and the CMMS to reflect changes in procedures and engineering

The pilot and implementation plan also accounts for the commitment of other resources supporting the effort such as frontline mechanics and technicians, maintenance management staff, and vehicle engineers. These resources will likely require additional training time and time to implement the proposed improvement and specific elements of the RCM process. The implementation plan addresses performance measurement and ensures that it is possible to collect data to properly validate the improvements, including the qualitative feedback of mechanics, technicians, and operators (7), (8).

Key Success Factors

- The department has a formal RCM process that covers selection of projects, project team composition and organization, and standard project steps and is updated regularly.
- The department has sufficient RCM project leaders in place with experience and expertise in the RCM process.
- The department's workforce is aware the need for and benefits of RCM and supportive of the process.
- The department selects employees with appropriate skills and provides appropriate training for RCM project teams.
- RCM project participants have a good understanding of the relative criticality of vehicle assets and vehicle functions and failure modes.
- The department maintains high quality system- and component-level historical performance data.
- There is a formal process in place to review and implement RCM project recommendations.
- When deploying RCM in a new area, the department uses a pilot project to introduce the process.

Total Productive Maintenance

The Total Productive Maintenance (TPM) approach provides an effective complement to the RCM approach. Whereas RCM focuses heavily on the technical elements of maintenance, TPM is more concerned with the quality and efficiency of maintenance processes and of their execution, with a particular focus on the human element of maintenance. Unlike RCM, TPM is not focused on a single process or improvement methodology. Rather, TPM is a management philosophy that sets forth a vision for maintenance programs to realize continuous improvement in efficiency, quality, and customer service (6). It is possible to apply TPM throughout the maintenance organization, including supporting functions not necessarily directly managed by the department, such as inventory management and information systems management.

Organizations across the world in diverse industries have adopted TPM and used it with success. It fuses preventive maintenance methodologies with "lean production,"[13] total quality management, and total employee involvement approaches pioneered in Japanese manufacturing. As the name implies, Total Productive Maintenance demands the involvement of the entire maintenance organization and focuses on using maintenance resources efficiently and maximizing the up-time and effectiveness of equipment, in this case the transit agency's rolling stock (14), (22). For purposes of implementation, Total Productive Maintenance can be organized around four pillars[14] presented in Figure 3-14.

Figure 3-14

Overview of the Total Productive Maintenance Approach

- **TPM Pillar #1: Maintenance Prevention and Process Improvement** – Maximize equipment availability and productivity. Employees continually apply and improve preventive maintenance practices to drive vehicles towards perfect performance and maximum "uptime" or availability while minimizing costs. Employees focus on continuous improvement of all maintenance processes to realize many small, incremental improvements for significant overall benefit.

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[13]The formal Lean Six Sigma performance improvement approach, which has been implemented in transit railcar maintenance programs, is well documented in *A Transit Methodology Using Six Sigma for Heavy Rail Maintenance Programs* (30). Zwas provides a useful overview of the "Lean" approach in the transit maintenance context (44).

[14]Note that there is no standardized definition of TPM. The pillars presented here are based on a synthesis of the literature tailored to the railcar maintenance context.

- **TPM Pillar #2: Customer and Quality Focus** – Establish a maintenance culture focused on quality and customers. Employees complete all tasks with an eye to quality and the end user. Employees must feel ownership of maintenance processes and accountable for meeting organizational goals and supporting continuous improvement.
- **TPM Pillar #3: Collaboration and Teamwork** – Emphasize a team-based approach to problem solving. Small, cross-functional teams can quickly respond to minor issues, identify improvement opportunities, and implement solutions which can then applied throughout the railcar maintenance program. Encourage collaboration between management and frontline workers to better align the maintenance program to pursue organizational goals and deliver continuous improvement. When all railcar maintenance workers have well aligned goals and incentives, they are better able to improve performance.
- **TPM Pillar #4: Continuous Learning** – Support ongoing learning in the maintenance program to ensure knowledge transfer, up-to-date skill sets, and quick response to emerging skill gaps. An organization committed to its employees' ongoing learning supports a more engaged workforce with a stronger commitment to quality and continuous improvement (23), (24), (25), (26).

For each of these pillars, TPM emphasizes the use of data to underwrite performance improvement and decision-making. Performance measurement ensures that TPM efforts are directed to the most critical and rewarding areas, improvements can be effectively tested, and their success verified. The following sections provide more detail on each of the four pillars and introduce improvement methods and tactics to support each pillar. Together, the TPM pillars and their supporting methods and tactics are an effective way to implement proactive maintenance, both as a strategy for addressing a specific target vehicle system and as a general maintenance strategy to improve performance across the department. Under TPM, small performance improvements across all functional teams and areas of maintenance contribute to significant overall improvements in vehicle and fleet performance (23).

Pillar #1: Maintenance Prevention and Process Improvement

The first of TPM's pillars is maintenance prevention and process improvement. The key goals of this pillar are:

- Maximum fleet availability
- Zero breakdowns
- Continual cost reduction.

To achieve these goals, maintenance workers focus on optimization of maintenance processes, standardization of maintenance procedures, improvement of the quality and precision of maintenance work, and reduction of maintenance errors. Supporting tactics include autonomous maintenance, process management, and management of human factors.[15] Each of these tactics can reduce the time and cost of repairs and improve the consistency and results of maintenance procedures. As a result, they improve equipment availability through better reliability and shorter mean time to repair. The following sections present each of these strategies in detail.

Autonomous Maintenance

Under the TPM approach, management sets performance goals[16] and places responsibility for meeting those goals on frontline employees. Managers are responsible for facilitating and coordinating improvement efforts, but frontline workers play a major role in identifying improvement opportunities and developing and testing improvements. Autonomous maintenance formalizes this structure as the policy of the railcar maintenance department. Under autonomous maintenance, frontline workers are explicitly held accountable for identifying and addressing maintenance issues, even those do not fall under their formal responsibility. For instance, even if a defect identified during a preventive maintenance inspection is not part of the PM checklist, the mechanic is still responsible for taking the time to log the defect and address the issue, and failure to do so should be noted as part of quality assurance audits. Similarly, in the course of any preventive maintenance or repair, mechanics take the opportunity to carefully clean, lubricate, inspect, and adjust the system and its vicinity (27), (6). If an issue is not part of an employee's typical duties, the employee is still responsible for initiating follow-up actions, such as referring the issue to the appropriate coworker.

Autonomous maintenance emphasizes training frontline workers to identify quality issues; for example, train operators and cleaners may be trained to check for common issues and log them as defects. A general principle of TPM and autonomous maintenance is that the first person who identifies an issue is responsible for ensuring it is addressed, either by personally carrying out the corrective action or by forwarding the defect to the appropriate specialist. With complex vehicle systems, many defects do not correspond to well-established failure modes. Autonomous maintenance emphasizes the ability of frontline workers to respond to unexpected issues and minimize any potential disruption. When managers find that issues are going unnoticed by frontline workers, autonomous maintenance requires that they follow up with all employees with responsibility for the vehicle system or maintenance process and resolve the issue (28), (6).

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[15]Note that any other performance improvement method or tactic that supports optimizing maintenance processes, standardizing maintenance procedures, improving the quality and precision of maintenance work, and reducing human errors in maintenance could be used to support this pillar of TPM.

[16]Detailed discussion of performance management is in Section 5.

Principles of Autonomous Maintenance

- Frontline workers ensure parts and systems are carefully cleaned as part of routine maintenance.
- Frontline workers actively identify and repair or refer all defects, especially in course of executing standard inspection protocols.
- Frontline workers receive cross-functional training to identify and make common routine repairs for quality issues they might regularly encounter in their daily work (e.g., cleaners addressing minor vandalism and train operators logging maintenance issues for follow-up).
- Management collects and distributes performance data to help frontline workers understand their performance and identify opportunities for improvement.
- Management ensures standardization of operation and repair protocols and checks and enforces compliance.
- Railcar maintenance staff collaborates with frontline workers in transportation operations and other maintenance departments to prevent the conditions that to lead to defects (e.g., educate train operators and security about the costs of addressing vandalism or work with rail maintenance staff to improve the rail-wheel interface) (6).

Rigid job descriptions can foster an attitude that anything falling outside a worker's job description is not his or her responsibility and hamper workers' collaboration. Such inflexibility is particularly a problem for smaller and short-staffed agencies. A heavy reliance on supervision can contribute to this problem by discouraging employees from proactively addressing issues and creating an adversarial relationship with managers (28). More flexible job descriptions, together with more self-management by frontline teams, is an important element of autonomous maintenance. The flat hierarchy of a self-managed team encourages team members to hold each other accountable for their work. When accountability is assigned to individuals and expectations are clearly communicated, they are given a sense of responsibility to achieve results and help employees understand how their actions can affect the overall workflow (29). Attaching accountability to specific agency goals can improve motivation and employee ownership of their work.[17]

Process Management

Process management is a second performance improvement method supporting TPM's maintenance prevention and process improvement pillar. Under process

[17]Accountability, goals, and performance measures are covered in further detail in Section 5.

management, a specific employee is designated as responsible for oversight of each maintenance business process or a specific component of the process. Examples of railcar maintenance business processes include a standard preventive maintenance inspection carried out by mechanics, an inventory process for component rebuilds, and an inspection protocol carried out by railcar attendants when a vehicle enters the maintenance yard. Process management encompasses tracking of the business process's resource use, ensuring the business process meets its objectives and performance targets, and ensuring performance issues are identified and addressed. The process management approach provides a framework for both stability and continuous improvement of the process[18] (24).

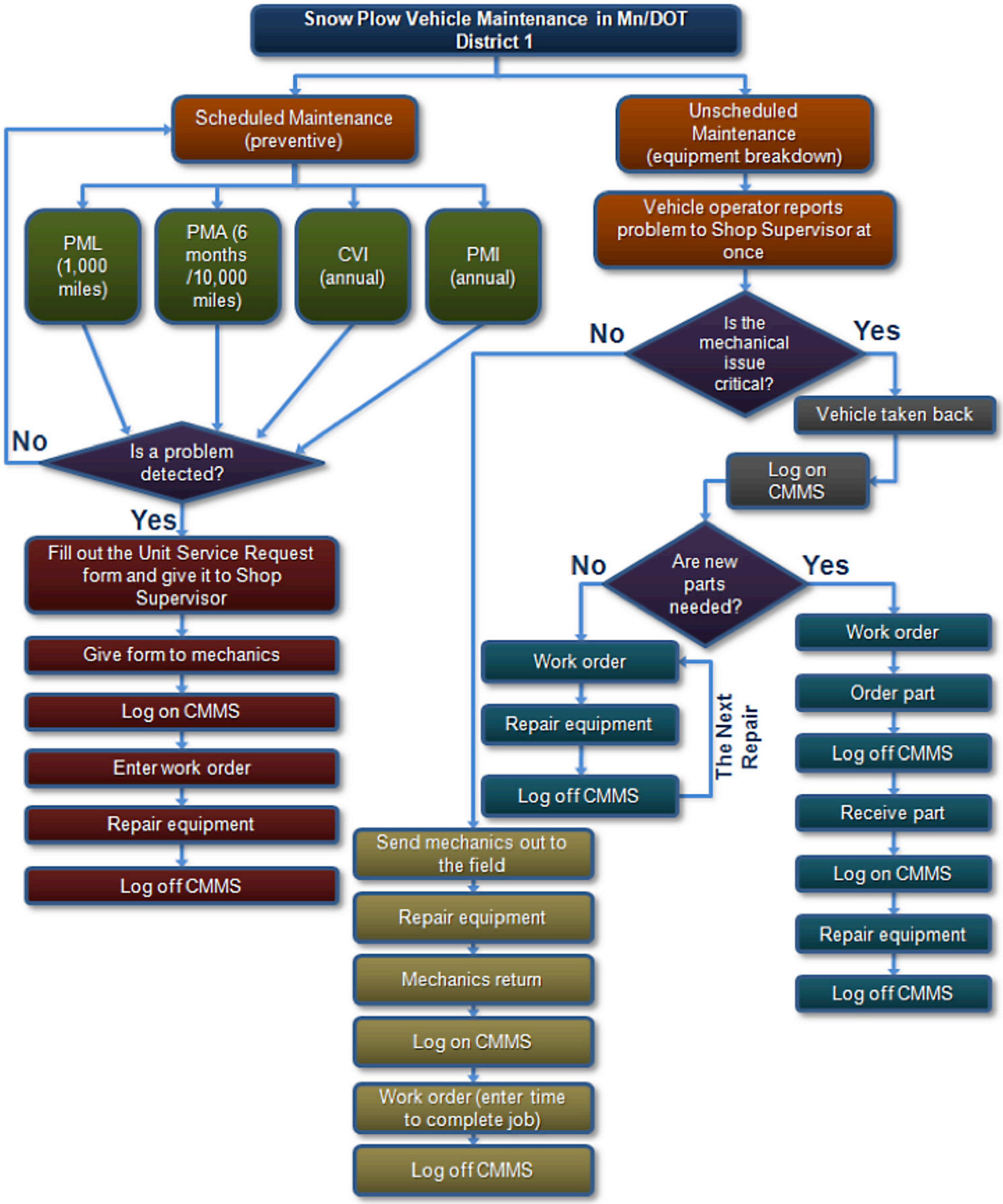
Designating a process owner ensures accountability for the process's performance. The process owner is responsible for proactively identifying and addressing performance issues and leading performance improvement efforts, including process re-engineering. The process owner collects feedback from all workers touching the process and regularly verifies the performance of the process through data collection and automatic reports from the CMMS or other management control systems. Process owners are also important internal resources, maintaining expertise critical to maintenance operations.

Process diagrams are an important tool to support process management and provide an official documentation of the process and to map its changes over time. Process diagrams describe the actions at each step, including any decision logic. A more detailed process diagram may also include the business function of each step, the employee responsible for overseeing each step, resource inputs and outputs, and performance measures for key steps in the process (30), (24). Figure 3-15 provides an example of a higher level process mapping for vehicle maintenance. Process diagrams can help workers to visualize processes spatially and understand where issues are arising.

[18]Process management is an important part of the Lean Six Sigma performance improvement approach, which has been implemented in transit railcar maintenance programs. Cook and Tyson-Wood describe the Lean Six Sigma methodology and provide several rail transit case studies (30).

Figure 3-15

Example Process Map for Vehicle Maintenance



Source: Adapted from Wilson, Dadie-Amoah, and Zhang (31)

Collection of performance data is another critical step in process management. Performance indicators can cover process inputs and outputs and measure productivity, efficiency, and quality and effectiveness. The process owner should be able to use performance indicators to effectively pinpoint performance issues and trends for investigation (24). Fleet maintenance departments often use methods such as statistical process control to monitor process performance and watch trends in defects and understand when the frequency of defects rises above normal bounds. Statistical process control uses CMMS quality control data to quickly identify when a systemic quality issue arises (32). More information on the selection and use of performance measures can be found in Section 4.

The process owner is responsible for overseeing any process re-engineering effort to address process performance issues. The re-engineering of a business process typically begins by defining the business requirements related to the process. Next, the process and owner and the quality improvement team should analyze how well the existing process fulfills those requirements. The team can either target key steps for reengineering or develop an entirely new replacement process if the existing process's performance is sufficiently poor. Often, the spatial configuration, process steps, and other elements of the process can be redesigned to improve efficiency and quality. The process owner may select one or more methods to support such business process re-engineering efforts. This report presents a variety of such methods, which range from the informal—like quality circles[19]—to the more analytical—like time studies[20] (33).

Process management also supports TPM through the standardization of procedures. When variations exist in the way workers carry out business processes, it can lead to variations in process outputs, including in efficiency and quality. Process management helps ensure that key business processes are carefully defined. Process owners are responsible for verifying that employees show discipline in adhering to the procedures defined for the process. Disciplined execution of process procedures contributes to quality assurance (6). Under the TPM approach, standardization of maintenance procedures can be a continuous process. Over time, procedures may be documented in further detail to optimize outcomes (14). For example, it may prove worthwhile to specify the torque applied to tighten a particular bolt as part of a particular component installation procedure. The process owner updates the electronic documentation with the new specification and adds the torque wrench to the standard toolkit in the maintenance job's description in the CMMS. Next, the engineering team may develop an easier measurement approach to improve the assembly precision for the part's installation, improving the accuracy of its alignment. Later on, cleaning and lubrication procedures may be updated to reduce the cleaning time and improve application of oil. Improving standardization and precision of maintenance procedures for critical systems and components can, over time, improve both reliability and maintainability.

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[19]For more on quality circles, see "Pillar #2," Customer Focus.
[20]For more on time standards, see on Section 5, "Performance Targets/Benchmarking."

Finally, the process owner is responsible for the regular review and update of process documentation. Ideally, electronic documentation is maintained in a format and system that make the update process easy, allowing the addition of new figures and helpful tips. When electronic maintenance documentation is more detailed and accessible, railcar mechanics and technicians are likely to make more frequent use of it. The documentation for a preventive maintenance procedure might include additional practical information such as diagnostic tests, parts needed, safety cautions, and quality checks. Safety checks can relate to hazardous chemicals, unsafe temperature, unsafe pressures, equipment position, or other factors. Quality checks may include specifications like proper pressure, wrench torque, or part condition. They may also include operation checks to ensure the effectiveness of the maintenance procedure (17).

Using Process Management to Improve Communication

Shift changeovers illustrate some of the advantages of improved communication processes. Not having a clear communication process in place can lead to maintenance error and confusion as to what work still needs to be completed. For example, a mechanic can spend hours trying to diagnose a problem, only to discover that the problem was already diagnosed during an earlier shift. Work status markers are useful for workers from the outgoing shift to communicate to workers of the incoming shift whether work is in progress or completed. This avoids wrongful assumptions that work has been completed on a piece of equipment when it has in fact, been not, or vice versa (28). Often, improved CMMS processes can help manage information flows and prevent communication gaps. On the other hand, inventory departments often face mechanics who do not fill out requisitions properly, for instance just taking parts from an unmanned storeroom on the graveyard shift, or who do not update requisitions as their needs change, leading to supply chain inefficiencies. Such cases illustrate both the need for effective communication processes and for a disciplined maintenance culture where workers adhere to those processes.

Addressing Human Factors in Railcar Maintenance

Many mechanical failures can be attributed to human errors during maintenance. Addressing human factors is a third approach to ensure maintenance quality and support implementation of the maintenance prevention and process improvement pillar of TPM. Surveys in the aviation industry have found that maintenance error was responsible for one in eight major accidents and one half of engine-related flight delays (34).

Human error is unintentional. It is the natural result of the fundamental unpredictability in human behavior in an environment where such actions can cause negative maintenance outcomes. Human factors describe the behaviors and circumstances that lead to human errors and provide a framework for managing them. Human factors are the emotional and mental properties of human behavior and capability and should be understood as another dimension to maintenance improvement. Analysis of human factors seeks not to blame employees for errors, but rather to identify and control characteristics of the task and environment that raise the likelihood of human error. Addressing human factors not only improves maintenance quality but can also streamline maintenance processes and improving process efficiency.

Human factors can be related to qualities of the worker, the maintenance equipment, the documentation or information environment, the workspace and physical environment, the organizational environment, and the specific characteristics of the maintenance task. Some critical human factors that can lead to maintenance quality and safety issues include the following:

- Lack of communication prevents information flow between employees and can lead to maintenance error. Good communication is especially important between employees working on the same maintenance activity, but on different shifts.
- Complacency can develop over time, especially with routine tasks that are performed repeatedly, but should be avoided to prevent overlooking potential risk.
- Distractions can disrupt maintenance tasks and prevent their successful completion. Distractions are not limited to those that occur in the working environment, they can also be mental in nature.
- Lack of teamwork prevents effective communication and the sharing of knowledge and can prevent a common goal from being reached. Teamwork is necessary for problem solving, troubleshooting, shift turnover, and coordination of maintenance activities.
- Fatigue and stress, both mental and physical, can impair judgment and lead to maintenance errors. A contributing factor to fatigue is shift work, which may often times fall outside an individual's normal circadian rhythm. Night shifts, in particular, make employees more susceptible to environmental disturbances.
- Use of inappropriate tools and parts can lead to employees completing a job improperly. When the right resources are not in place, individuals have the tendency to problem-solve and complete the task anyway, often with an impact on final quality.
- Pressure from managers or downstream workers can affect an employee's performance and ability to execute a maintenance task correctly.
- Lack of assertiveness can result in concerns that are not made known. It is essential that employees have strong communication between peers, supervisors, and management.

- Lack of awareness and focus is common for tasks that are performed time and time again.
- Norms are the ways things are typically done—however, norms may not always be safe and can be counterproductive. They can develop as a result of a problem that does not have a straightforward solution. It takes an often difficult culture shift to shift poor norms and, instead, rely on standard practices and procedures.
- Poor physical condition of a maintenance worker can also contribute to maintenance errors. If a mechanic has poor eyesight or motor skills relative to the average worker, it may be reflected the quality of the person's work (35), (36).

There are four general approaches to address human errors:

1. The first and usually least-intensive approach to address human factors is to ***improve the information environment*** through improved instructions and modification of tools and techniques to reduce the likelihood of the human error.
2. Another approach is to ***provide training*** to maintenance staff—for instance, to improve situational awareness, communication, and team skills that have been shown to reduce errors due to human factors.
3. Maintenance staff may also address human errors through ***process reengineering*** to address critical human factors in the job design which lead to human errors. Such an approach requires careful data collection and testing to verify the root problem and validate the approach.
4. Finally, it may be possible to address human errors in a maintenance process through the ***improvement of the workspace and work environment***, using tactics like mistake proofing and implementation of a visual workplace strategy (see call-out boxes below) to provide better visual cues for maintenance workers. The overall organizational culture is also a part of the working environment. An ideal organizational culture is collaborative, has strong communication at all levels, and fosters support and guidance of its employees (36).

Approaches to mitigate human factors include:

- Put in place measures to ensure awareness of common hazards, including high voltage lines, perched objects, heavy objects, moving equipment, and hazardous materials.
- Put in place physical guards to protect against these same hazards.
- Provide clear and full instructions for the maintenance procedure, if possible and helpful on the equipment itself.
- Improve accessibility to the system on the vehicle through special tools and positioning the vehicle or by removing the system from the vehicle.

- Provide, on the equipment if possible, warnings of hazards and recommend safety measures such as protective gear.
- Clearly note where a maintenance task requires special training, tools, or maintenance equipment.
- Put in place checks and fail safes to mitigate the likelihood of serious hazards.
- Ensure the reassembly order of components is clear.
- Provide easy verification for out-of-tolerance operation on safety critical vehicle systems and maintenance equipment and ensure workers check these.
- Ensure there is an indicator for when fail safes are activated and that workers make sure to check the indicator.
- Provide training in ergonomics to limit injuries from poor lifting or working position.
- Ensure careful preparation for all maintenance work and avoid rushing any tasks.
- Make sure workers log all safety-related defects like corrosion, including for maintenance equipment and workspaces.
- Rigidly enforce all safety procedures, including the most routine aspects like appropriate shop dress and workspace cleanliness and log all safety incidents, including near misses.
- Ensure similar parts and materials can be easily identified and distinguished, an issue particularly with small commodity items like bolts and nuts.
- Log maintenance errors including type and follow up even when they have not lead to a failure or safety incident since errors may indicate human factors issues which might be of consequence in the future (37), (36).

Mistake Proofing

The tactic of mistake-proofing, also known by its Japanese name "poka-yoke," works to address human factors introducing common human errors in a maintenance process that lead to defects and other quality issues impacting reliability. Quality assurance, engineering support staff, or frontline workers identify recurring mistakes and redesign the process either to provide easy checks for the mistake or to minimize the probability of the mistake occurring in the first place. The mistake proofing process is also intended to streamline QA/QC into the production process and improve overall efficiency (14).

Visual Workplace

A visual workplace uses visual management and communication to quickly convey timely information in maintenance work spaces. Visual controls are an efficient way to ensure quick, accurate assessments or decisions, minimizing errors from human factors and improving maintenance efficiency. Visual systems and controls also help reduce unnecessary motion to carry out tasks. On equipment, a visual control can include noting or marking desired operating ranges to allow quick testing. Simple fault sensors can serve as efficient visual controls. For instance, temperature sensitive tape can be used on critical components to detect overheating. Other examples include:

- Markings to guide proper installation direction
- Color-coding fluid caps, bottles, or storage areas to avoid use of the wrong fluid
- Transparent doors to give visibility to compartments for quick assessment
- Pneumatic line color conventions to avoid misidentification of onboard pneumatic systems
- Use of barcodes or RFID to allow each scanning to identify part numbers
- Action boards to give the status and trends associated with a particular vehicle or vehicle system
- Color-coded dashboards to help prioritize actions such as nearly due or overdue preventive maintenance actions
- Photographs and drawings to support documentation of procedures in maintenance manuals (14).

Educating railcar maintenance employees on these measures helps ensure they are included as part of the department's performance improvement processes, including, for example, RCM, process management, and quality circles. Many obvious human factors issues are best addressed in the procurement process. For example, modern railcar maintenance facilities use layout, barriers, and color-coding to address human factors and improve safety. Where possible, design reviews in the procurement process should specifically address human factors.

Human Factors and Workplace Safety

Human factors often interact with higher risk activities to create workplace safety incidents. Therefore, it is particularly important to control for human factors in environments and situations with systemic risk. Work in confined spaces, around high voltage lines and suspended loads, or in proximity to vehicles or mobile equipment are especially associated with serious worker injuries. Likewise, the improper adherence to lock out tag out protocols and the improper use of physical safety guards and barriers and safety controls for high temperature and pressure equipment and hazardous materials also lead to a high share of serious worker injuries in transit. Addressing human factors related to such precursor events can help mitigate human errors that lead to safety incidents (50).

Pillar #2: Customer and Quality Focus

The second of TPM's pillars, a focus on customers and maintenance quality,[21] helps maintenance workers to understand their role within the overall transit organization and reinforces individuals' accountability for maintenance outcomes. Linking daily maintenance activities to customers and quality can also help motivate the workforce by instilling a sense of purpose in the maintenance program and investing mechanics and technicians in their work. The customer focus (see later subsection) involves bringing maintenance staff closer to the customer base and working more on maintenance issues of critical concern to customers. The quality focus (see later subsection) involves an extended commitment to measuring, verifying, and improving the quality of maintenance work.

Zero breakdowns, zero accidents, zero injuries, and zero defects are clear TPM goals that frontline workers can easily understand and work towards (14).

Customer Focus

TPM's customer focus provides a basis for the railcar maintenance department to prioritize its efforts. Customer feedback ensures awareness of customer needs, expectations, and any shortfalls in meeting them. For a railcar maintenance program, its customers include both the transit passenger and internal customers. For example, materials and inventory staff should be in close touch with shop customers—the end users of the parts. Likewise, specialty shops, like electronics, should seek regular input from downstream customers within the railcar maintenance program to ensure the shop's workflow is effectively prioritized. The railcar maintenance program as a whole

[21]Work quality is a central focus of TPM, so it should be no surprise that it features prominently not only in discussing Pillar #2 and its supporting tactics but also in discussing the other pillars.

serves the operations department, ensuring revenue vehicle availability and reliability and responding to mechanical incidents. If organizational goals are carefully defined, the needs of all customers should be closely aligned (26). Customer feedback can come from frontline employees, surveys, focus groups, and customer service call centers.

Through their daily interactions with customers, frontline and interface employees (interface employees are those who interface with an upstream or downstream function) often have practical insight into customer needs and issues with existing maintenance practices. Formal processes to collect feedback from these employees can help ensure their insights are communicated to the appropriate functional team (24). Railcar maintenance managers can get direct feedback from customers through formal surveys, interviews, comments made to customer service agents or through feedback cards. Managers can also directly track measures of service quality and passenger satisfaction, such as ridership, mechanical reliability, and vandalism.

For internal customers, like transportation operations, there can be a formal feedback process in place with defined goals and performance measures, such as for vehicle availability. Examples of internal feedback mechanisms include a regular customer survey, feedback forms when specific issues arise, and a follow up process when a maintenance team does not meet expected service levels. Cross-functional working groups and quality circles (see call-out box below) are also effective feedback and problem solving approaches.

Vehicle maintenance managers can ensure that passenger satisfaction measures related to the maintenance program's work receive a high profile within the department. From the perspective of maintenance, mechanical reliability is consistently seen as the most critical component of service quality, along with the comfort and cleanliness of vehicles (22). A customer focus can also help underpin a healthy maintenance culture where employees have sustained commitment and motivation to execute their roles well and deliver quality work (28).

Quality Circles

Quality circles are informal problem solving groups associated with a functional team or a specific business process that meet regularly to address previously identified performance issues. Typically the scope of the issues addressed in a quality circle is fairly narrow. Issues are usually process-related and not overly-technical. Technical or overly complex issues are better addressed by a quality improvement team in a dedicated project. Usually, one to three issues are addressed in a single session, lasting no more than an hour. Often, a manager or team leader facilitates and ensures a consensus for action is reached by the end of the meeting. Letting employees drive the process helps ensure it is relevant and effective. Managers should encourage employees to take ownership and adapt the process as they see fit (57). Quality circles can use any brainstorming or problem solving technique that the participants deem appropriate, but methods usually emphasize a visual approach and the participation of everyone. At the end of the meeting, participants identify, prioritize, and take responsibility for action items (60). A subsequent quality circle may be needed to revisit and review actions and pursue further progress on the issue. However, each quality circle meeting should be treated as a discrete opportunity to address the issue. A simple log kept by the facilitator can help track the progress and accomplishments of the quality circle over time and help understand its contribution over the long term.

TPM's customer focus promotes a preventive in mentality. Employees should always be asking how to prevent the issue in the first place and how to streamline processes to better serve their customers, whether the end user (the passenger) or an internal customer. When defects and failures do occur or a team fails to meet a service level, it is important that employees take the time to evaluate the incident and understand its causes. If necessary, a team may conduct a follow up investigation and target the issue for improvement (6).

Maintenance Quality Assurance

TPM seeks to make maintenance quality the responsibility of every railcar maintenance worker. Improving maintenance quality requires a combination of improving maintenance practices' effectiveness and quality assurance measures to ensure maintenance procedures are properly executed. Since Pillar #1 has already covered the first aspect of quality improvement—process improvement, this section focuses on quality assurance. Rolling stock maintenance programs use diverse quality assurance processes, both formal and informal. Formal measures can help ensure the consistent application of quality assurance checks and hold individuals accountable for maintenance quality. Formal quality assurance measures include preventive maintenance inspections, random quality control inspections, dedicated quality control staff on the shop floor, internal quality audits, follow-up on vehicle operation performance issues, and follow up on repeat failures (17).

Post-maintenance testing is among the most intensively used quality assurance measure. The goals of post-maintenance testing are to:

- Ensure that the worker has successfully completed the maintenance procedure.
- Ensure no new defects have been introduced during the work completed.
- Ensure the vehicle system is prepared for revenue service.

Post-maintenance testing is usually necessary after corrective maintenance and often for preventive maintenance, depending on the criticality of the system and the maintenance error or success rates for the system. A worker can conduct an effective testing procedure on the spot with minimal effort with the following considerations:

- The testing employee needs competence with any measurement tools or apparatus, and it is also helpful for the worker to understand conceptually how the test works.
- Importantly, the test must be predictive of the repair's actual success.
- If equipment tested is subsequently failing, the testing method needs to be updated to improve its precision and accuracy or to expand its scope.
- Recording quality test and check results in the CMMS helps ensure that the worker has carried out the test and preserves the information for future analysis, including of the test's effectiveness (37).

Random spot checks and inspections by dedicated quality assurance staff are the most common strategies for checking the quality of preventive maintenance work. A 2010 survey of North American transit agencies revealed that 79 percent have some quality assurance measures in place for maintenance and 41 percent perform spot checks. It is important that the quality assurance staff follows up on each deficiency identified by the check. The original mechanic or technician performing the maintenance should receive immediate re-training if possible and the issue should be logged to track workers' performance over time. In some agencies, quality assurance staff directly oversees a mechanic's work as part of spot checks. The quality assurance specialist double checks the mechanic's work to ensure measurements, tests, and other procedures follow standards and demonstrate the correct method as necessary. Quality assurance staff may also be needed to oversee the work of vendors (38).

Auditing is another common approach to quality assurance for railcar maintenance. Quality assurance audits rely on impartial observers, usually trained quality auditors,[22] to reveal where maintenance workers have deviated from maintenance plans, maintenance standards, or agency policy and practices. Beyond correcting such shortcomings, a careful audit also offers the opportunity to develop

[22]For instance, the American Society for Quality has a Certified Quality Auditor professional designation program.

recommendations for process improvement—both at the technical and organizational levels—that can help drive improved maintenance performance. The failure of maintenance staff to finish a procedure or to carry it out correctly can lead to additional costs from component failures and service disruptions. Quality assurance audits are also an opportunity to benchmark an agency's current practices against industry best practices at a detailed level, and they help to update management assumptions, such as desired performance levels for a given asset or function. When there is a standing quality assurance audit function, performance reports can document the results for upper managers at an appropriate interval: monthly or quarterly or as the audit results come out. Quality assurance audits can cover the maintenance organization's full range of functional areas including:

- Organization and staffing
- Labor productivity
- Management training
- Planner training
- Craft training
- Motivation
- Management and budget
- Work order planning and scheduling
- Facilities
- Stores, materials, and inventory
- Preventive maintenance and equipment history
- Condition monitoring
- Work measurement and incentives
- Information systems.

The agency's ability to meet standards in each area can be scored and an overall maintenance program audit score created. Likewise, it is possible to use detailed scoring for each element of the individual audits. Audit recommendations flag specific issues for follow up and weight the recommendation by criticality. For each recommendation, the audit identifies the individual responsible for addressing it; managers can then track every recommendation through to its resolution. Auditors may include internal staff from the maintenance program, staff from peers or agencies with oversight responsibilities, internal audit staff, or consultants (39).

A good audit process should be non-adversarial. It emphasizes transparency and collaboration with key stakeholders to identify specific steps to address audit recommendations. An agency's response to audit recommendations is an important indicator of its management culture and commitment to accountability. For instance, basing the quality assurance audit on a random and representative sample of maintenance jobs underscores the impartiality of the process and helps it not to appear punitive.

For an audit to have an effective outcome, it is important to present the process as an investment and allocate extra budget/resources for follow-up. Addressing audit recommendations should be an opportunity for employees to gain exposure within the organization—a high profile task rather than just a compliance exercise. Importantly, an audit should include, if necessary, a mandate for substantive change from the executive level to ensure the organization can move forward with changes.

TPM emphasizes the value of a preventive approach to assure maintenance quality and of the leadership role that frontline workers can play in guarantying and improving quality. TPM relies the deployment of diverse methods and tactics to help managers and frontline workers successfully devise and deliver improvements focused on preventing errors and defects and ensuring maximum initial quality. One example of such methods is the 5S methodology (described in the box below), which focuses on creating an environment that minimizes human error. Mistake proofing (see later subsection) focuses on the prevention of specific errors. Quality circles (see later subsection) provide employees with an opportunity to identify and address specific issues in short sessions dedicated to problem-solving (30).

Metro Audit of Railcar Preventive Maintenance Practices

The Los Angeles County Metropolitan Transportation Authority's (Metro) Inspector General's 2011 audit of railcar preventive maintenance (62) provides an example of a high quality audit, identifying several areas of concern including incomplete or poorly completed preventive maintenance activities. If items on the preventive maintenance checklists are not completed or are completed poorly, the condition of railcar systems can deteriorate rapidly and lead to in service failures and more costly unplanned repairs. In the case of Metro's audit of preventive maintenance, auditors found that traction motor brushes were not replaced for several railcars in the audit sample despite wearing beyond minimal limits. Preventive maintenance procedures dictates that these parts be inspected as part of the 22,500 mile inspection. Worn brushes can damage the motor's commutator, which is substantially more expensive to replace than the low cost brushes. Because the brushes cannot be expected to last until the next 22,500 mile inspection, the commutator can be damaged sufficiently to cause the propulsion system to fail entire, creating an even more costly failure event.

Critically, the auditors used work order records from the CMMS to trace the issues back to particular personnel and follow up with them. Identifying specific issues and tracing back their root causes ensures maintenance staff can develop and implement effective improvement measures to address the audit issues. The internal audit report identified specific follow up actions backed up by high level management scrutiny. The Metro example shows the importance of the audit process a quality assurance measure, especially in large agencies, to prevent major deviations from standard business practices when other management control measures fail.

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5S Methodology

The 5S methodology is another technique from Japanese total quality management practices. 5S stands for (1) Seiri or "Sorting Out," (2) Seiton or "Systematic Arrangement," (3) Seiso or "Shine," (4) Seikutsu or "Standardization," and (5) Shitsuku or "Self-Discipline." Frontline employees can deploy the 5S methodology to improve the operational efficiency of their maintenance work stations and raise their productivity and quality.

- "Sorting out" refers to the elimination of superfluous or redundant elements of a process, including preparation, instructions, procedural steps, and parts. This process addresses unnecessary complexity, makes a process more clear, and reduces the possibility of human error.
- "Systematic arrangement" or "straightening" is a principle focused on the reorganization of tools, equipment, and workspaces to ensure the most frequently used items and spaces are conveniently located and easy to identify. This process reduces time spent finding and retrieving appropriate tools and moving between workstations.
- "Shine" or "spic and span" underscores the need for a clean, tidy workspace. This principle ensures that succeeding shifts find well-kept workspaces ready for use and that workspaces remain organized and efficient.
- "Standardizing" emphasizes that workstations and procedures for a specific job should be identical. Employees should be able to use any workstation for the same job and should be able to complete any partially complete job. This process reduces setup time and promotes flexibility in operations.
- "Self-discipline" or "sustaining the practice" refers to the need to maintain improvements and adhere to procedures. Without self-discipline, performance and improvements deteriorate over time (14), (25).

Pillar #3: Collaboration and Teamwork

The third pillar of TPM, collaboration and teamwork, provides an important foundation for continuous performance improvement. Collaboration and teamwork help ensure all maintenance workers understand and participate in the department's performance improvement processes. Furthermore, the collaboration and teamwork pillar focuses on breaking down organizational silos and building cross-functional collaboration and an organizational culture where all maintenance and supporting workers have aligned goals.

Quality improvement teams are a common strategy for frontline performance improvement to bring stakeholders together to address maintenance operations issues. Like RCM project teams, quality improvement teams provide a structured process for collaborative performance improvement, but focused more on maintenance processes than on vehicle systems. Change management is another important strategy for coordinating large-scale change and involving stakeholder. Continuous improvement demands frequent changes in the way the department does business, and often these changes are major. Change management provides a framework for ensuring participation in and support for the process based on planning, collaboration, and teamwork. Note that collaboration and teamwork are also embedded in the many of the methods presented in support of the other three TPM pillars. For example, self-managed teams, process management, quality circles, and change management all promote collaboration and teamwork. At a more basic level, a general focus on renewing the agency's maintenance culture can help instill collaboration and teamwork as foundational values and also reinforce the implementation of TPM's other pillars and is discussed further in Section 6.

Quality Improvement Teams

Quality improvement projects provide critical support to the TPM approach. Like RCM projects, quality improvement projects identify target performance issues through a critical, independent assessment, such as a criticality analysis. Quality improvement projects may respond to issues identified through the performance management system or independently by employees. Target issues are typically complex problems related to process improvement rather than engineering issues which would be covered under the RCM approach (24). Quality improvement projects typically focus on railcar maintainability, either directly or indirectly. Improving the efficient delivery of parts is one example of an issue indirectly related to maintainability – more timely delivery of parts can help improve overall repair times. A new quality check instituted in a maintenance procedure is an example of an improvement project directly related to maintainability. The new quality check improves maintenance effectiveness by reducing the likelihood of a comeback and subsequent repair to the same system.

Once a target issue has been established for a quality improvement project, the manager should assemble a quality improvement team (QIT). An effective QIT resembles a RCM project team. Success factors include the following:

- The QIT should have a project sponsor and a manager responsible for monitoring the project.
- Teams typically have a leader responsible for managing the team's work and ensuring focus and progress. Team leaders should have a proven ability to moderate among team members and manage projects.

- Cross-functional teams offer a more complete understanding of the entire maintenance process. Depending on the technical complexity of the target issue, the QIT might involve mechanics and technicians, materials staff, process or mechanical engineering staff, quality assessment staff, and foremen or more senior maintenance managers. Some maintenance organizations may need to keep consistent teams because of their small size.
- The size of the teams should be commensurate with the scope and degree of the target issue. Small teams typically make faster progress and better engage individual members.
- Depending on the team's focus area, it may meet temporarily or on an ongoing basis. Teams with more dedicated time usually find it easier to collaborate and make rapid progress. Providing significant dedicated time to performance improvement teams is one way for managers to show their commitment to the process (14), (24).

Quality improvement projects should have clear and specific goals: for example, a 15 percent reduction in the time the process takes. Such goals provide the team with a concrete focus and allow easy assessment of the project's success. An eight-week term is a common standard for improvement projects, typically followed by a test phase where the QIT pilots the proposed improvement to verify its effectiveness based on objective measurement (24).

The quality improvement team may select one or more problem solving methodologies to tackle the target issue. Ideally all team members have direct experience implementing the approach selected, but at the very least, the team leader should (24). While RCM emphasizes a quantitative analytical approach to maintenance improvement, TPM relies on a mix of management, engineering, qualitative analysis, and problem solving tools to achieve process improvements. Such tools include Pareto analysis, statistical process control, problem solving techniques (like brainstorming and functional diagramming), team-based problem solving, mistake-proofing, autonomous maintenance, continuous improvement, setup time reduction, 5S, waste minimization, benchmarking, bottleneck analysis, A/B testing, reliability, maintainability, and availability (RMA) analysis, recognition and reward programs, and system simulation (14). The team may also facilitate quality improvement exercises, such as quality circles, mistake-proofing, and visual workplace improvements.

A/B Testing

A/B testing is an analysis method to test a potential change before fully adapting it. A/B testing best targets process changes in a complex environment where the influence of a single factor is difficult to observe and determine. The proposed improvement is implemented on a test set of vehicles or employees which resembles the overall population in all key respects. Managers select a measure of effectiveness to compare the two populations, preferably with data collected automatically through the CMMS. The effectiveness measure should target the variable changed as closely as possible, for instance the failure rate of a particular vehicle system rather than the overall vehicle failure rate, so as to minimize the influence of unrelated effects on the measurement. The test period should be of an appropriate length to register any difference accurately. In many cases, it is possible to establish a statistical confidence level with the data collected. It is important to measure both groups simultaneously to limit the effect of other factors on the effectiveness measure. A/B testing results can help determine both the success and cost-effectiveness of a particular change to a maintenance process, such as a change in preventive maintenance procedures, the effectiveness of a training, or the use of a new vendors for a part or service.

Change Management

Change management is a process to help agencies navigate major organizational transitions and can help agencies move forward with new ways of doing business as part of TPM. Change management relies on the development and execution of a plan to support and transition of employees through the major change. The process involves careful planning to prepare for the change by anticipating impacts and resistance, then continually monitoring the change once it has been implemented. Overcoming resistance is perhaps the most difficult part of a major change such as the implementation of a new CMMS, and getting buy-in from the entire maintenance department and other agency departments is crucial to gain support to champion the change. Change can only happen once employees have the motivation and understanding for its need. Rather than dismissing resistance from employees, management should make an effort to understand the resistance in order to overcome it. Employees should be involved in the feedback process; their involvement is critical to make improvements and secure buy-in (40). Change management relies on the following foundational elements:

- Present the need for change persuasively: Define a clear rationale to establish the need for change and a clear vision of the desired outcome from change.
- Identify and consult with stakeholders: The people affected by the change have an opportunity to review the proposal and provide input throughout the process.

- Provide an action plan to implement change: An action plan provides a transparent roadmap to implementation of change, including resources required, a communication plan, and clear timelines.
- Establish broad organizational leadership for the process: Leadership at all levels throughout an organization driving a change helps ensure its success.
- Focus on the people: Plan for the training, communication, counseling, coaching, and other assistance necessary for employees to successfully support the process and transition to the new culture.
- Track the change process: Ensure that the process successfully meets goals and milestones and prepare to respond and adapt to any issues that arise.

Success factors include having in place strong program governance with clearly defined leadership, accountability for all implementation steps and supporting actions, and roles and responsibilities for all staff. Middle and upper managers provide strong leadership and role modeling for the change process and effectively communicate the vision and urgency of change. Finally, it is important to have an ongoing commitment to the change that endures beyond the project itself to institutionalize the change (41), (42).

Change Management at Turin's Public Transit System

When Turin's transit operating company, Azienda Torinese Mobilita (ATM, now Gruppo Turinese Trasporti), began to plan for its partial privatization in the late 1990s, the company's managers realized the importance of a comprehensive change management process to ensure a successfully transition. In response to an operating environment where ATM would face higher accountability for service quality and cost-effectiveness, the agency instituted an ambitious investment program, worked toward ISO 9001 and 14001 compliance, revised labor agreements to better align employee incentives to support performance. As part of the change management process, ATM's managers worked to involve employees at all levels and from all functions in the process, especially in setting performance targets and reaching consensus about reorganizations. ATM worked to increase transparency of its management culture and decision-making, sharing more information and developing more rigorous and objective promotion practices. Overall, the ATM navigated the transition successfully and remains the primary operator of Turin's public transportation system (42).

Pillar #4: Continuous Learning

Continuous learning is the fourth pillar of TPM.[23] Continuous learning envisions the railcar maintenance department as a learning organization committed to ongoing development of the workforce and includes the following characteristics:

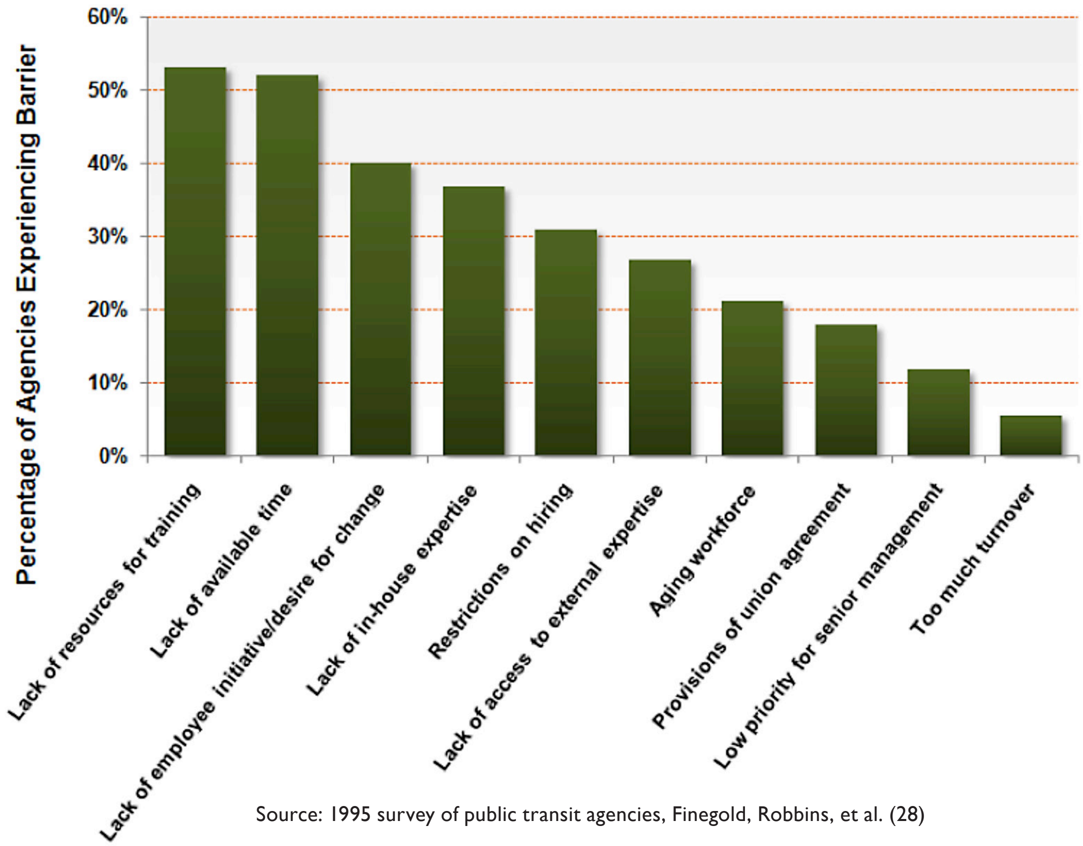
- Railcar maintenance employees have access to diverse learning opportunities including formal classroom training, informal on-the-job training, and outside third party education.
- Training is selected and prioritized based on the objective needs of the department.
- The railcar maintenance department emphasizes learning and development for all employees, regardless of function, rank, or tenure.
- Learning emphasizes both technical skills and soft skills, like teamwork, communication, and coaching.
- The department encourages peer education where frontline employees train and education each other.

Training is the most important element of developing a railcar maintenance department into a learning organization. The implementation of TPM requires both initial training as part of the change management process as well as a commitment to ongoing training and the development of the railcar maintenance program into a learning organization. TPM encourages maintenance employees to think broadly about their job responsibilities and their role in achieving the department's goals. Training empowers employees to focus on quality and conduct autonomous maintenance by broadening their skills and knowledge to help drive the process. Figure 3-16 shows some of the main reasons transit agencies have difficulty maintaining and improving the overall skill level of fleet maintenance workers. Committing to becoming a learning organization can help a railcar maintenance organization overcome many of these barriers.

[23]Note that additional material related to this pillar of TPM is discussed in Section 6.

Figure 3-16

Barriers to Mechanics' Skill Development



Source: 1995 survey of public transit agencies, Finegold, Robbins, et al. (28)

Training might cover technical skills such as certification for the use of key equipment, learning new tests, calibrations, and quality control measures, and diagnosis and fault analysis methodologies. It might build foundational knowledge such as principles of electronics or engine function. Finally, training might focus on developing soft skills, including communication, project management, and leadership. Employees with a more holistic understanding of the maintenance process are better equipped to have insights into performance improvement and to understand their own responsibilities within the organization. Likewise, better trained employees are more likely to recognize opportunities for performance improvement (14). Because of its importance in railcar maintenance management, workforce training and organization development are addressed in detail in Section 7.

The learning organization approach provides a broad-based approach to training, learning, and skill development. Learning organizations aim to boost interaction and knowledge sharing among employees by creating opportunities for learning both through training and daily work, promoting the development of soft skills to improve team-based work, and encouraging continuous improvement (28). There also needs to be an understanding of the agency's mission and goals in order for worker empowerment and ownership to follow. Critical general knowledge and skills to support TPM's success include:

- Quality and customer awareness: maintenance managers must ensure that all railcar mechanics, technicians, and support workers understand their customers' needs and the organization's commitment to quality. They should clearly understand how this relates to their daily work and how they will be held accountable for the quality of their output and their performance against customer-oriented goals.
- Coaching skills: managers and team leaders must be equipped to facilitate problem solving, solicit input, and support employee development.
- Quality improvement methodologies: frontline workers should have the opportunity to learn specific TPM process improvement methodologies to deploy in their daily work and as part of quality improvement teams (24).

The process of becoming a learning organization requires addressing any communications gap between supervisors and the frontline workforce. Fostering an environment where employees can not only provide feedback, but are given significant opportunities for input and control, together with accountability, encourages knowledge sharing and can prevent disconnects between how tasks are done and frontline workers' perceptions of how they should be done.

Lessons for TPM Implementation

TPM implementation begins with the commitment of the railcar maintenance department's top managers to the initiative. Managers at all levels are responsible for communicating the importance of the initiative to frontline staff. Champions for TPM are critical to drive the process and maintain progress. TPM relies on sustained commitment; implementation can easily last three to five year. Managers must demonstrate an ongoing commitment to TPM and hold staff at all levels accountable. Business plans, trainings, and business processes need to reflect TPM goals and provide resources to support the organizational transformation to implement TPM. It can be helpful to recognize and promote success stories and the individuals and teams driving them (14). Typically, a management working group is dedicated to ongoing oversight of the TPM process (24).

The implementation of TPM in railcar maintenance relies on significant preparation steps, which can be included in the department's regular annual planning. The implementation steps detail specific goals and responsible staff members, performance measures, and milestones. First steps usually include the training of supervisors and other management staff. It is important to have staff in place with sufficient expertise, including appropriate technical skills and practical experience implementing TPM, to support TPM initiatives (24). Another important success factor is to engage with frontline workers and union leadership and ensure there is an understanding among these groups about the need for and logic behind the implementation of TPM measures (14), (43). As part of this outreach process, it is helpful to identify evangelists within the organization who can take ownership of the project within the different functional areas of the organization and drive implementation to engage all employees who actively express interest in the initiative and harness their enthusiasm (24).

Continuous improvement consists of maintaining past progress and incrementally increasing the performance standards to ensure continual improvement. Managers can develop continuous improvement plans which focus on the most promising areas for performance improvement and allocate resources to identify and address specific performance issues and opportunities. Note that resources allocated to continuous improvement should be in proportion to the expected improvement. Continuous improvement plans should outline the organization and roles of workers at all levels with respect to the improvement process. Managers should test different performance improvement approaches and attempt to involve all maintenance employees in the improvement program (14).

As part of the initial commitment to TPM's implementation, managers may also identify strategic areas of focus. These may include implementation in a particular functional team or facility, or the initial focus may be on particular elements of TPM. Setting milestones for progress to achieve the overall vision can help ensure TPM's success. Breaking implementation into attainable pieces helps measure progress and consolidate gains in each area of focus (24), (14). Using a pilot project (for instance, in a particular shop or facility) to tackle TPM on a smaller scale lays a foundation for implementing the approach more broadly. The pilot project should have a clear impact from TPM and its successes should be apparent. Ideally, TPM eventually will become a part of the culture of the agency; its processes should extend beyond organizational practices to the behavior of agency personnel (27).

Key Success Factors

- Employees use ongoing customer feedback to allocate maintenance resources and improve maintenance practices.
- There is a quality assurance program in place including inspections, audits, and follow-up processes.
- The department uses quality improvement teams to improve target maintenance processes and outcomes.
- Quality improvement teams include broad participation of maintenance staff.
- The department supports its employees' continuous acquisition of skills and knowledge.
- Critical maintenance procedures and business processes have clear ownership, are clearly documented and standardized, and are reviewed regularly for performance improvement opportunities.
- The department's teams hold regular quality circles both within and across functions.
- Employees have good awareness of human factors' role in railcar maintenance outcomes.

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SECTION 4

Railcar Maintenance Planning Processes

This section describes the planning activities that railcar maintenance managers should be supporting at all levels of an agency—from agency-wide strategic planning to capital planning to day-to-day maintenance staff work plans. This section covers the importance of planning processes for the direction and implementation of the overall fleet maintenance program and the ongoing performance and condition of the railcar fleet.

Generally, planning processes are the first step to translate a transit agency's vision and goals down to the department level and then into implementation of concrete actions. A planning process reconciles end goals with available resources and provides a defined path to a specific set of outcomes. A planning process identifies specific work requirements, allocates resources and a reasonable budget, and defines an approach for completing the work. For railcar maintenance managers, planning is important for their day-to-day work activities and in support of the agency's capital program and operating budget processes to verify the department can achieve the following objectives:

- Meet the fleet requirements of the transportation operations department.
- Control fleet lifecycle costs generally and maintenance costs in particular.
- Ensure a high quality experience for the customer.

Through a coordinated planning approach, the railcar maintenance department can ensure its maintenance practices are aligned with the agency's goals and performance objectives while remaining consistent with available funding and resources. Strategic plans, lifecycle management plans, work planning, and other planning processes related to the railcar fleet are intended to document decision-making, guide the development of the fleet capital program and maintenance department operating budget, and, ultimately, provide roadmaps for delivering rail service that is as safe, cost-effective, and reliable as possible. Cross-functional planning efforts include service planning and procurement planning where the railcar maintenance department does not lead the planning process but is a key stakeholder (1).

Effective railcar maintenance planning processes result in:

- **Improved support of agency goals**: When railcar maintenance department representatives are involved in an agency's strategic planning sessions, it ensures that railcar maintenance plans align effectively with the agency's overall goals and strategy and with other departments' work programs. Moreover, the railcar maintenance group can ensure that the goals and performance targets are attainable based on the department's capabilities and capacity.

- **Proactive maintenance approach**: Effective lifecycle management planning is an important foundation for improving the fleet's preventive maintenance program and reducing reactive maintenance levels, as well as for establishing effective performance improvement processes.
- **Continuous improvement:** Railcar maintenance programs are complex operations that must respond to evolving vehicle technologies and needs, compliance with manifold regulations, and work in complex operating environments. Planning in railcar maintenance not only covers fleet needs but also those of the supporting facilities and equipment, human resources, materials management, and information technology. High quality planning processes can help ensure investment in ongoing improvement and to help anticipate challenges and make preparations to cost-effectively avoid them or mitigate their impact.
- **Improved stakeholder understanding and communication:** A clear definition of an agency's goals, including clear links between overall agency goals and specific frontline goals, as well as communication of progress made toward achieving the goals can improve relations with stakeholders both within and external to the agency through increased transparency.
- **Stronger agency accountability:** A clear understanding of agency-wide goals and performance measures that can be tied to the railcar maintenance goals and performance measures increases transparency and accountability. It ensures resources are allocated efficiently and the workforce's productivity and performance is maximized.

Railcar Maintenance's Role in Planning

There are four typical agency planning processes critical to fleet management that the maintenance department should either participate in or direct. Table 4-1 describes each of the four planning process and outlines the railcar maintenance department's role more specifically.

Table 4-1

Key Planning Processes For Railcar Maintenance

Agency Planning Processes	Planning Activities	Railcar Maintenance Role
Strategic Planning	Goal-setting process where agency's strategic direction and associated performance measures are established. The strategic planning process will, ultimately, determine the agency's priorities with respect to service and expansion, as well as how the agency will use its resources, including staff and funding.	• Provide input into strategic planning process, including the railcar maintenance department's role in the overall agency strategy, department capabilities and capacity, performance management, and department initiatives and challenges. • Confirm that goals, objectives, and performance measures are attainable based on maintenance department's resources and capacity.
Service Planning	Based on level of service goals, agency's passenger service schedules are established. Service planning is also associated with the development of the agency's Long Range Plan and its Fleet Management Plan, which outlines the agency's fleet requirements.	• Provide input into service planning discussions to ensure that that plans are attainable based on available resources and expected fleet condition. • Identify investments needed to support planned future service, both in the immediate future and in the longer term. • Ensure Long Range Plan and Fleet Management Plan consider maintenance implications of future projects and procurements.
Lifecycle Management Planning	Prioritize capital projects and maintenance plan and budget based on fleet condition and performance. Ensure fleet, facilities, and equipment investments and maintenance activities support fleet performance goals and minimize long-term fleet costs.	• Develop railcar lifecycle management plans to guide the fleet preventive maintenance program, rehabilitation programs, performance improvement, and new vehicle purchases. • Identify workforce, facilities, and equipment investments necessary to effectively carry out maintenance and overhaul work.
Budget and Work Planning	Detail maintenance program implementation, including establishing preventive maintenance strategy, work processes, staffing levels, parts requirements, facility needs, and performance improvement processes.	• Lead the development of the department's maintenance strategy, including predictive and preventive maintenance activities and performance improvement processes. • Identify types and levels of work needed to complete lifecycle management activities (maintenance and rehabilitation). • Budget and assign department resources to complete expected fleet maintenance and support activities. • Coordinate with Human Resources, Information Technology, Purchasing and Materials Management, and other departments to implement maintenance strategy and ensure staff, materials, software, etc. are in place and effectively managed.

The following sections describe the railcar maintenance managers' role in each of these agency planning processes in more detail.

Railcar Maintenance's Role in Strategic Planning

An agency's strategic planning process identifies the overall goals and priorities for the agency over the short and long terms, and it is important for a railcar maintenance department's staff to understand how their work fits within the agency's broader goals. The railcar maintenance department is responsible for ensuring that the fleet is available to provide safe and reliable transit service, and the agency's strategic plan determines the scope and intensity of the department's work. For example, an agency strategy to improve farebox recovery might involve commitments to efficiency and quality improvements in fleet maintenance; likewise, an agency's geographic expansion and rising service levels would require a supporting fleet management strategy to support increased fleet size, changing service geography and patterns, and new vehicles. The strategic planning process ensures that the agency's broader goals and strategies are aligned with the railcar maintenance department's own strategy, capacity, and capabilities. The experience of Chicago's Regional Transportation Authority in the call-out box below highlights how strategic-level decisions at the agency and metropolitan planning organization levels can translate into improved asset management practices in a railcar maintenance department.

Chicago Regional Transportation Authority Condition Assessment

Through the 1980s and early 1990s, Chicago's rail transit system underwent a sustained decline in its condition. After initiating a major rebuilding program in the 1990s that took many rail facilities out of service for extended periods, Chicago's Regional Transportation Authority (RTA) made the decision to move toward a condition-based capital programming model. The new approach began with an overall condition assessment of the assets of the region's three transit agencies. Through this assessment, RTA identified 23 percent of the region's transit railcars as having a condition rating of poor, including 18 percent of active railcars already beyond their useful lives. The condition assessment also showed that RTA had substantially underestimated capital investment and maintenance needs overall. For railcars alone, the overall capital investment backlog to maintain a state-of-good-repair was estimated at $5.9B.

RTA has committed to regular update of its asset inventory through ongoing condition assessments. RTA's new capital programming process now screens projects based on their safety, state-of-good-repair, and regulatory compliance impacts and prioritizes system maintenance over expansion and enhancement for capital funding. The agency's capital programming performance measures are also focused system maintenance:

- Shares of funding dedicated to maintenance, enhancement, and expansion
- Investment backlog to maintain a state-of-good-repair
- Percent of assets in good condition
- Percent of vehicles beyond useful life
- Miles between major mechanical failures

This capital planning approach has translated into a renewed focus on fleet maintenance and rehabilitation for the region's transit agencies. It also supports the use of procurement strategies such as best-value procurements (see Section 7, "Best-Value Procurement") to ensure the acquisition of vehicles with better reliability and maintainability and lower overall lifecycle costs, as well as a stable fleet preventive maintenance program. Finally, RTA's capital planning approach encourages the railcar maintenance program to play a role in mitigating overall capital costs through a productive maintenance program which emphasizes a lifecycle approach. The region's transit agencies are now implementing enterprise asset management systems, which will support ongoing collection of condition data, supporting not only capital programming but also ongoing performance improvement and their own lower level maintenance and capital planning (8), (10), (9).

As Figure 4-1 shows, the railcar maintenance group should be providing input into the agency's strategic planning processes, but they should also be taking the outcomes of these strategic planning meetings and incorporating them into their maintenance strategy and performance management practices (1).

Figure 4-1

Railcar Maintenance Role in an Agency's Planning Processes

Railcar Maintenance's Role in Service Planning

A transit agency's service planning function is typically responsible for determining how to structure bus and rail service to best address the agency's goals. Ultimately, the service planning function develops schedules that specify the level of service that customers expect to receive every day. To be able to meet these schedules, the railcar maintenance department should provide fleet availability levels by time of day, day of the week, and ongoing (based on retirements, new vehicles, and rehabilitation programs), and confirm that service plans developed are attainable based on available maintenance resources and expected fleet availability and condition. The agency's service levels determine the fleet utilization and service miles, which translate directly into preventive maintenance requirements and estimated corrective maintenance levels and help determine the overall railcar maintenance budget. Therefore, service planning requires input from the railcar maintenance department to ensure the service levels can be achieved within the constraint of the overall operating budget. Usually, it is an iterative process to find a level of service balancing fleet capabilities, ridership demand, and fare revenue (see call-out box below).

Reconciling Service Planning with the Fleet Operating Budget

As part of one commuter rail agency's annual budget process, the staff creates a "ridership budget"—the expected ridership for the forthcoming year based on planned service levels. The agency uses the ridership budget to estimate fare revenue. Before the final budget is approved, the agency works to reconcile the service plan, ridership forecast, and fare revenue to ensure that the agency does not commit to unsustainable revenue service. If the planned service cannot generate sufficient ridership and fare recovery, then the service plan is rebalanced to an acceptable level (12).

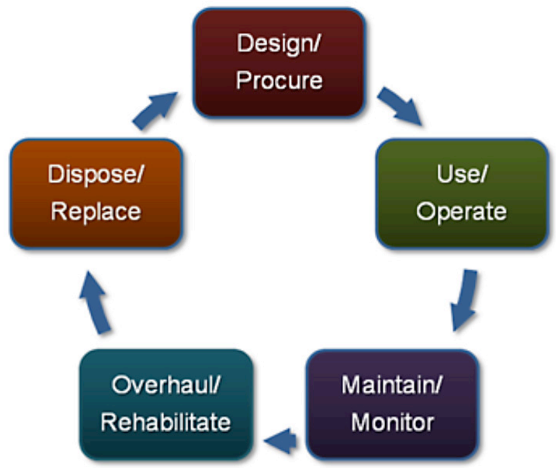
Over the long term, service planning is reflected in the agency's long-term plan. The long-range plan reflects the agency's prospects for upgrading and expanding the system. The long range plan must be consistent with the fleet management plan, which describes the agency's fleet requirements to meet the service levels planned over the long term. Railcar maintenance managers are responsible for ensuring the fleet management plan reflects realistic assumptions for meeting the long-range plan's service levels. Historical data from the computerize maintenance management system (CMMS) and fleet condition assessments help provide an analytical basis for a realistic fleet management plan. Such data helps to develop more accurate forecasts of future fleet capabilities and funding needs. The railcar maintenance department is responsible for using such information to verify that maintenance budget levels in the long-range plan are consistent with the expected needs of the railcar fleet as set forth in the fleet management plan.

Railcar Maintenance's Role in Lifecycle Management Planning

As described in the FTA's *Asset Management Guide* (61), a lifecycle management plan documents the costs, performance, and risks associated with an asset class throughout its useful life and the associated activities to address and optimize each of these factors. Lifecycle management plans are featured in this section because they are a valuable planning tool to help railcar maintenance programs think comprehensively about their diverse fleet management activities, improve cross-functional collaboration, and better allocate maintenance resources and capital funding. Lifecycle management plans can also document the department's strategy for deploying ongoing performance improvement approaches like Reliability-Centered Maintenance and Total Productive maintenance.

A lifecycle management plan explicitly draws connections between each phase of a railcar's lifecycle (see Figure 4-2) to ensure actors in each phase collaborate with upstream and downstream stakeholders and maintain a broad understanding of their goals and responsibilities in the asset lifecycle. Most importantly, the lifecycle management plan can directly support the agency's capital programming and O&M budgeting processes, as well as the department's own budget and work planning processes.

Figure 4-2
Lifecycle Management Activities



The fleet management plan is often the closest document most transit agencies have to a lifecycle management plan for railcars. Examples presented in this section show how agencies have developed fleet management plans and railcar maintenance plans that effectively serve the functions of a lifecycle management plan. When a formal railcar lifecycle management plan is in place, the agency's railcar maintenance department is typically the owner of the plan, responsible for its development and update. Potentially, an agency could have a lifecycle management plan or sub-plan for each railcar model or have a single plan that covers all of an agency's railcars.

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

- Provides a basis for data-driven, informed fleet capital investment and preventive maintenance decisions to minimize overall lifecycle costs;
- Establishes performance improvement processes to maximize the reliability and maintainability of the fleet throughout its lifecycle;
- Identifies specific employees responsible for each railcar lifecycle management activity, including supporting roles such as IT and inventory management support;
- Improves fleet lifecycle cost and performance through the documentation of formal cross-department coordination processes over the course of a railcar's useful life.

The contents of a lifecycle management plan will vary depending on the level of asset management maturity for the railcar fleet. While a less mature lifecycle management plan will focus simply on defining preventive maintenance strategies and practices, a more mature lifecycle management plan will include policies for condition assessment practices, performance monitoring and improvement, guidelines for the management of documentation of procedures and plans for preventive and reactive maintenance, practices for managing facilities and equipment resources, and collaboration with related functions like purchasing, inventory, and capital programming. A mature railcar lifecycle management plan also addresses the railcar maintenance department's performance improvement approach, including deployment of strategies like RCM and TPM, and critical labor issues such as training and skills development and technology needs and management.

Factors Defining Fleet Investment and Lifecycle Management Requirements

Fleet management plans are required by FTA and typically fulfill many of the functions of an asset lifecycle management plan. Southern California's commuter rail service, Metrolink, developed a fleet management plan based on a comprehensive analysis of both supply- and demand-side factors determining fleet needs, as shown below.

Demand-Side Factors

- ❖ Demand Analysis
  - Forecast growth in passenger trips and passenger miles
  - Service expansion
  - Load factors
- ❖ Regulatory requirements
  - EPA diesel engine requirements
  - Positive train control
- ❖ Railcar upgrades
- ❖ Safety improvements
- ❖ Passenger improvements

Supply-Side Factors

- ❖ Current railcar inventory
  - Capacity
  - Mileage
  - Service usage
  - Lease agreements
- ❖ Vehicle utilization rate and spare ratio
- ❖ Rehabilitation/overhaul requirements
- ❖ Analysis of available funding by source and allowable purpose

Although the plan is relatively brief, it prepares a thorough analysis, including multiple scenarios based on the framework above, resulting in a well-defined plan to allocate limited resources for railcar maintenance, rehabilitation, and replacement. The plan only covers only five years, a shorter timeframe than typical, which may have the benefit that, as the plan is updated more frequently, it has greater value as a practical, living document (13).

For each process, activity, or technical standard mentioned the lifecycle management plan, it is helpful to include a reference supporting documentation that provides a higher level of detail. A lifecycle management plan is one way to track key maintenance documentation and ensure it remains up-to-date. A lifecycle management plan can also be used to ensure that the performance expectations of the railcar fleet are understood and fit within the agency's broader goals and performance objectives, and that all investment decisions are transparent and well communicated. Table 4-2 provides the recommended contents of a railcar lifecycle management plan.

Table 4-2

Lifecycle Management Plan Contents[24]

Section Name	Contents Description
Roles and Responsibilities (Who is responsible for this railcar fleet's lifecycle management activities?)	Outlines roles, responsibilities, and accountabilities for the railcar fleet's lifecycle management, including designating a manager responsible for overall fleet lifecycle management and cross-functional coordination.
Fleet Inventory (What assets are included in this lifecycle management plan?)	Introduces the railcar fleet, including: • Inventory and criticality of assets • Expected changes in the inventory • Expected service requirements.
Fleet Policy and Strategy (What are the asset management goals for this railcar fleet?)	Outlines any policies and strategies related to this railcar fleet. It also explains how the railcar fleet's lifecycle management activities support the broader asset management policies and goals (including level of service requirements and sustainability outcomes).
Condition Assessment and Performance Monitoring (How will the railcar fleet's performance be measured and monitored?)	Outlines the fleet's current condition and references the documented railcar fleet-specific approach to condition assessments and performance monitoring. This includes outlining when the railcars should be inspected, how inspections will be conducted and condition measured, and what actions should be taken based on the rating assigned.
Preventive Maintenance Plan (What activities can be proactively completed?)	Outlines the preventive and predictive maintenance approach[25] to maximize the performance and minimize the costs of this railcar fleet. This section also describes the resources (costs, staffing, materials, etc.) needed to meet expected rolling stock maintenance needs and links these to fleet performance.
Rehabilitation and Replacement Plan (What capital investments are needed?)	Outlines the rehabilitation and replacement approach[26] to maxe the performance and minimize the costs of this railcar fleet. This describes the resources needed (costs, staffing, materials, etc.) and explains and links to performance.
Lifecycle Management Supporting Functions (What are additional activities are necessary for maximizing the performance of this railcar fleet?)	Outlines all remaining lifecycle management activities, including considerations and strategies regarding procurement, warrantees, materials and purchasing, information technology, and disposal. This section also describes the resources needed from other departments, including IT, HR, etc.
Capital Program and Operating Budget (How will asset management support capital programming and operations and maintenance budgeting?)	Forecasts the capital and operations and maintenance budget and other resources needed to address the lifecycle needs of this railcar fleet. The budgeting timeframe should match the agency's overall capital and operations and maintenance budgeting timeframes. This section may also cover expected lifecycle costs of the fleet.
Performance Modeling (How will asset condition data support scenario evaluation?)	Identifies how available data can be used to evaluate how well the railcar fleet is achieving its level of service, sustainability, and other performance goals. Historic data (compiled into decay curves) and current data can be used to monitor performance over time and forecast how different funding levels can impact performance in the future.
Continuous Improvement (How can we ensure we continue to get better at managing this railcar fleet?)	Outlines how the railcar maintenance department manages performance improvement, including overall framework and specific processes and strategies. This section should capture any key challenges facing the department and fleet, together with specific actions to address these and progress in doing so. Additionally, it should reflect the process for maintaining the lifecycle management plans.

Source: Rose, et al. (61)

[24]Lifecycle management plan contents will vary depending on the level of asset management maturity associated with the railcar fleet.
[25]This section may be developed based on the original equipment manufacturers' (OEM) guidelines; however, adjustments should be made reflecting past experience and local requirements, in consultation with the OEMs if possible.
[26]*Ibid.*

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Ideally, a lifecycle management plan is developed as part of the railcar fleet's procurement stage to ensure it is designed and manufactured in a way that considers the railcar's performance requirements, maintainability, equipment and facility needs, and total cost of ownership. However, it can be created at any time and should be updated regularly as maintenance and other lifecycle management practices change. Key implementation principles associated with lifecycle management planning include the following:

- While many parties will likely provide input into the plan, there is a railcar fleet "owner" responsible for coordinating the development and upkeep of the lifecycle management plan. The "owner" is typically a representative from the railcar maintenance department.
- Lifecycle management plans are developed with input from all departments that are involved in the railcar fleet's lifecycle. Represented parties likely include procurement, engineering, transportation operations, maintenance, and capital planning. Representatives may also support a cross-functional technical advisory committee supporting cross functional performance improvement.
- When possible, require the original equipment manufacturer (OEM) to document in detail the lifecycle management requirements (including scheduled maintenance and overhaul requirements, testing and diagnostic equipment, and drawings and other technical documentation) as part of the railcar fleet's procurement with consideration for the agency's specific operating environment. An agency's operating experience with the fleet and funding availability may lead to different actions, but the OEM provides the baseline lifecycle management practices.
- An agency evaluates cost, risk, and performance to determine the optimal amount of preventive maintenance for the railcar fleet. There is an optimal amount of planned maintenance for railcars that minimizes the cost of planned vs. reactive maintenance. This evaluation requires experience, understanding of railcar deterioration, repair methods, and, ideally, the use of analysis tools.
- Lifecycle management plans support the performance measurement system and set key performance targets and benchmarks for the railcar maintenance program. They are continually updated to reflect changes in the operating environment, condition assessment technologies, and manufacturer guidelines.
- Railcar maintenance staff review and update lifecycle management plans as part of the budgeting process. The owner should use the railcar lifecycle management plan not only for fleet and resource planning, but also to track reviews of and updates to preventive maintenance practices, workforce development activities like training, and performance improvement activities.

- Lifecycle management plans are continually updated to reflect changes in the operating environment, condition assessment technologies, and manufacturer guidelines.
- Lifecycle management plans are made available on an agency's intranet (or other shared file location) so management and staff can freely access the information.

Chicago Transit Authority Rail Car Maintenance Plan

The Chicago Transit Authority's (CTA) Rail Car Maintenance Plan provides a counterpoint to Metrolink's Fleet Plan, focusing on the railcar maintenance department's role and providing much more detail on maintenance-related lifecycle management activities. The document provides an overview of the department's preventive and capital maintenance (capital maintenance can include equipment upgrades, overhauls, and rehabilitations) resources and practices.

It begins by outlining the agency's railcar maintenance goals. Key goals cover vehicle availability (defined as sufficient vehicles to meet scheduled service), reliability (mean miles between reported defects), budget (cost per vehicle mile), overtime use, scheduled vs. unscheduled maintenance share (based on cost), and facility cleanliness.

The maintenance plan proceeds by describing the agency's fleet, including upcoming changes, and maintenance resources, including staff, facilities, equipment, CMMS, and training. The plan devotes special attention to the role of the Rail Engineering and Technical Services (RETS) group, which provides ongoing engineering support for new vehicle and other procurements, technical support for maintenance, purchasing, other functions, quality assurance including QA/QC of CMMS data and post-maintenance QA inspections, quality improvement support such as trainings, development of manuals, and reliability studies. The heart of the Rail Car Maintenance Plan is its overview of the scheduled maintenance program. It defines each preventive maintenance inspection, the quarter-life overhaul, and the mid-life overhaul. Finally, the plan covers the expected costs of the maintenance program. The plan's appendices reference key supporting documents, including bulletins, manuals, training programs, and sample reports.

CTA's 1986 railcar maintenance plan emphasizes maintenance budgeting and vehicle replacement planning. The 2010 maintenance plan shows an evolution toward a broader strategy that manages and allocates CTA's railcar maintenance resources based on high level strategies and a performance measurement framework. CTA's current maintenance plan provides an effective roadmap for a lifecycle management approach to maintaining the agency's railcar assets (11) (14).

Railcar Maintenance Budget and Work Planning

While the lifecycle management plan looks at the overall maintenance program, it needs the support of more detailed budgeting and work planning of activities to effectively predict and manage costs and resources. For instance, the implementation of a new maintenance approach such as total productive maintenance (see Section 3, "Total Productive Maintenance") requires program planning to underwrite the change management process. Work planning would include mapping out specific implementation steps, assigning staff time, and developing a program budget and schedule.

Work planning usually begins with the development of the railcar maintenance department's annual work plan and budget. The work plan and budget provide the specific detail necessary to implement the actions identified in the lifecycle management plan and the capital plan, as well as any special projects identified by the railcar maintenance director. The budget and work plan accounts for expected major events in the year, such as a major procurement, new maintenance equipment, facility work, new technology or updates, especially to the CMMS, and rehabilitations. The budget is based on asset histories and forecasts to provide the most realistic scenarios possible.

The railcar maintenance department's operating budget is typically developed using a bottom-up, activity-based approach, starting with at the level of the individual railcar. Two year budgeting is a common practice to create a more workable time horizon (3), (4). A more detailed approach with bottom-up data helps to ensure the accuracy of the budget and reduce the risk of unforeseen costs and issues (1).

Development of a bottom-up operating budget and work plan include the following actions:

1. Use asset inventory—including vehicle age, condition data, and maintenance backlog—to compile expected maintenance needs—including all preventive maintenance requirements and the likely level of corrective maintenance.
2. Compile costs (labor, materials, contracted work, etc.) associated with expected maintenance needs.
3. Identify any supporting activities to be considered (process development, training, performance improvement).
4. Identify any investments to be considered (new software, new equipment, facilities upgrades, etc.).
5. Make initial budget request.
6. Prioritize activities based on final budget.
7. Develop schedule of activities based on funding available.

The development of the annual work plan and budget is an opportunity to communicate with teams and departments in maintenance and identify potential issues. The process helps commit the maintenance organization to the plan.

For the operating budget, agencies typically use a line-item cost model. Fixed costs such as software licenses and facility operation costs do not vary with the level of maintenance service provided and should experience less variation. Variable costs may depend on a variety of factors, including the actual fleet miles and reliability (1), (5). Sophisticated agencies support their cost modeling with scenario analysis to show how varying funding levels impact key performance indicators, such as fleet reliability, availability, backlog, and condition to support decision-making (6), (7). In order to ensure consistency, elements of the maintenance operating budget may correspond to activities defined in the railcar lifecycle management plan.

Once the work plan is in place, each of its components can be mapped to a particular budget line item. Managers put the work plan into action by scheduling and assigning work orders, such as programmed preventive maintenance inspections, and projects. As the work orders are completed, they debit costs from the assigned budget line item in the accounting system. An important feature of a contemporary CMMS is that it provides a high detail of financial transparency, tying work to resources like employees and assets like vehicles or vehicle systems. The traceability of costs gives managers insight into the cost of work plan activities, the value they create, and trends in both over time. Management can use the data to evaluate productivity, capacity, and backlog. The work order system also provides the basis for activity-based costing, which is useful for budgeting because managers can project the needed maintenance activities over the budget period and project costs based on the historically required resources, such as labor, parts, and equipment, and their associated costs (3), (4).

Key Success Factors

- Representatives from the railcar maintenance department are involved in the agency's strategic planning process. Maintenance should be an equal party in agency-wide planning processes related to fleet and service planning.
- Railcar Maintenance should participate in strategic planning, service planning, and financial planning discussions to ensure that funding allocations for fleet management—including labor, information technology, materials, and training—support the agency's overall service strategy.
- Managers provide input to the long range plan and the fleet management plan to ensure these consider the maintenance implications of future capital projects, service expansions, and vehicle procurements.
- Railcar maintenance staff supports railcar procurement and design activities to ensure that new rolling stock is easily maintainable and its total cost of ownership is minimized. Railcar fleet lifecycle management plans are an important tool to formalize such collaboration.
- Managers use lifecycle management plans to improve management of the fleet's performance and lifecycle costs and inform their capital and operating budget decisions.
- Managers develop an annual or biennial work plan that implements the strategies and actions identified in the fleet lifecycle management plans.
- The department bases its annual operating budget on bottom-up work planning.

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SECTION

5

Performance Measurement for Fleet Management

This section describes how railcar maintenance managers can use performance measurement to monitor implementation of the maintenance program and align complex operations with overall department and agency goals. The section covers how to select performance measures, establish a baseline, communicate performance data, and use performance measures to support decision-making.

Introduction to Performance Measurement

As part of their oversight and direction of the railcar maintenance program, managers need to know what maintenance work is being performed and whether it is realizing the intended outcomes. Performance measurement is a data-driven management control approach to track all activities and investments throughout the railcar's lifecycle against an agency's goals. Typically, these goals revolve around service levels, customer satisfaction, safety, and cost-effectiveness. In support of these enterprise goals, the railcar maintenance department has key objectives related to the following areas:

1. Meeting the fleet requirements of the transportation operations department
2. Controlling lifecycle costs in general and maintenance costs in particular
3. Ensuring a high quality experience for the customer

Within the railcar maintenance department, the performance measurement function provides a ground-up framework for tracking and delivering these objectives and evaluating the effectiveness of the department's railcar maintenance strategies. The department's performance measurement program monitors all major business processes—such as the fleet preventive maintenance program, in-service incident response, inventory management, project management of capital projects, and workforce planning—with the intent of linking decision-making to the railcar's overall lifecycle management and the agency's overall goals.

An effective performance measurement program has the following benefits for the railcar maintenance program and fleet operations:

- Assists managers in setting implementation milestones and ongoing performance goals that support the agency's overall objectives

- Measures progress in reaching milestones and achieving the overall strategy and objectives, identifies emerging performance issues, and supports continuous performance improvement
- Improves communication of and accountability to the railcar maintenance department's overall business strategy and goals
- Ensures consistency in objectives among all organizational levels of the department
- Provides an objective baseline for comparison (especially when benchmarked against other transit agencies or related industries)
- Provides a framework for decision-making around performance issues (1), (2), (3), (4)

Performance measurement is also a way for managers to communicate with frontline employees and share a vision throughout the maintenance organization. Maintenance departments are as prone to operating in silos as any other organization. Because they do not necessarily interface directly with transit operations staff or transit customers, railcar maintenance employees may sometimes not be well engaged with the overall enterprise goals. Performance measurement is an important management tool to help workers understand their own performance and connect their own work with upstream and downstream activities and to the agency's overall objectives.

This section shows how the performance management process can help railcar maintenance managers direct their efforts and improve their decision-making. It describes how railcar maintenance managers can establish and use high quality performance measures. It also covers some practical considerations regarding performance measurement, including the use of the computerized maintenance management system (CMMS) and data quality assurance. Managers and staff can use the information to improve their oversight of the maintenance railcar program and better understand how to improve operations. Table 5-3, at the end of this section, provides example performance measures across the railcar maintenance functions.

Establishing Railcar Maintenance Performance Measures

A performance measurement program collects information from diverse sources within the organization and packages it in performance reports for specific audiences to inform their decision making, planning, and actions. Performance data sources include condition inspections, day-to-day maintenance activities, periodic audits, or on-board vehicle technologies. Railcar maintenance managers need to identify performance measures that will be useful, informative, and timely for various agency stakeholders. This section describes how to select such performance measures.

Types of Railcar Maintenance Performance Measures

Each performance measure typically relates to a particular railcar maintenance activity or process and needs to provide clear information on the railcar maintenance program's success in implementing a specific goal. Most performance measures fall under the five performance characteristics related to either maintenance process inputs or outputs.

- **Efficiency** measures look at maintenance inputs and consider the level of resources used to produce a certain level of output. For example, standard work times provide an efficiency benchmark which managers can compare against actual work times from the CMMS. A vehicle system's mean cost to repair is another measure of efficiency.
- **Productivity** indicators are similar to efficiency measures but focus on output, measuring the level of production over the course of a given time period. A maintenance team's output level in repairs per hour, shift, or week is an example of a productivity performance measure.
- **Quality/Effectiveness** measures focus on outputs and evaluate the degree to which the organization's output meets operational requirements and expectations. Quality/effectiveness measures are often customer-focused. Mean distance between failures is one measure of service quality related to railcar maintenance.
- **Timeliness** measures also evaluate maintenance outputs and examine the extent to which the actual work completed conforms to the planned work schedule. The percentage of preventive maintenance completed on-time is a measure of railcar maintenance timeliness.
- **Safety** and related measures look at both maintenance inputs and outputs and track the ability of the organization to complete its work while maintaining the well-being of its customers, employees, and third parties. Near misses are a measure of worker safety and an example of an input-side performance measure for safety. The condition of safety-critical systems provides one example of an output-side measure of safety performance (3), (5).

Note that a given performance measure may cover multiple characteristics. For example, peak hour revenue vehicle availability measures both productivity (how many peak service vehicle hours the maintenance department is delivering from the existing fleet) and service quality and effectiveness (how well the maintenance department is meeting the needs of the transportation operations department).

Another consideration in selecting performance measures is to look at leading vs. lagging indicators and the use of aggregate indicators.

- ***Leading indicators*** are measurements of some aspect of the transit system that provide an early indication of success or failure in meeting a goal. Leading indicators are valuable because they allow the transit agency to anticipate issues and avoid unnecessary costs. For example, condition monitoring allows maintenance staff to forecast failure risk for vehicle systems and components and allows mechanics to proactively address issues and better time maintenance activities. Condition-based maintenance helps transit agencies avoid the costs of both unnecessary repairs and of failures. As another example, the size of the preventive maintenance deferment or backlog is a leading indicator for future reactive maintenance levels and overall maintenance costs and capital needs.

- ***Lagging indicators*** are measurements of the transit system that provide an "after the fact" measurement of success or failure in meeting a goal. A lagging indicator is less preferable but is often the easiest information to collect. For areas where trends emerge slowly, the time delay for a lagging indicator may not be a significant drawback. As an example of a lagging indicator, employee productivity measurements could serve as a lagging indicator of the effectiveness of a training course (5).
- ***Aggregate indicators*** can be helpful to summarize performance information to an easily digestible level of detail. For example, some maintenance organizations use an overall index to track performance broadly over time. Overall equipment effectiveness (OEE) is one such performance index and is discussed in the call-out box below. However, managers should recognize the limitations and drawbacks of aggregate or high-level performance measures which, for instance, can wipe out differences in performance apparent across assets, teams, and locations (3).

Overall Equipment Effectiveness

Overall equipment effectiveness (OEE) is the preferred single performance index for the total productive maintenance approach because it captures multiple key measures of maintenance performance. The idea behind an OEE metric is that many small improvements can have a measurable aggregate effect and that overall performance is the most important focus of a maintenance organization. The OEE metric is the product of three factors: vehicle availability, productivity, and performance. For transit vehicle maintenance, these factors are defined as follows:

$$Availability = \frac{Total\ \ Time\ Available\ for\ Operation}{Scheduled\ Time}$$

$$Productivity\ = \frac{Total\ Actual\ Kilometers}{Scheduled\ Kilometers}$$

$$Quality\ = \frac{Number\ of\ Runs\ without\ Failure}{Total\ Runs}$$

OEE is defined *as*

$$OEE\ =\ Availability\ \times\ Productivity\ \times\ Quality.\ \ (15)$$

Finally, the performance management program should comprehensively cover the department's maintenance activities. It helps managers understand whether the organization is effectively deploying resources to execute its planned work and whether the railcar vehicle maintenance department is achieving its overall goals. Examples of work activities to monitor (potentially in a dashboard report), includes:

- Railcar lifecycle management activities, including daily inspections, preventive maintenance inspections, system overhauls, and, as applicable, vehicle overhauls, engineering, and procurement activities
- Key projects, like a major rehabilitation program, an important engineering project, like the upgrade of a propulsion system, or an important supporting project, such as the implementation of a new CMMS
- Department resources, including its workforce, equipment and facilities, and budget.
- Key support processes and business systems, such as purchasing and materials management and performance of the CMMS

> It is important to avoid falling into the trap of only measuring what is easy to measure. Transit agencies must ensure their performance reporting provides a comprehensive view of maintenance operations. Including some things simply because they are easy to measure (e.g., mean time between failures) and excluding other things that are difficult to measure (e.g., cost to complete maintenance activities) is counterproductive. With a new performance measurement system, it may be necessary to adjust business processes or reporting practices to collect new data. What is most important is the value of the data collected (3).

This report covers each of these areas and provides example key performance indicators for each at the end of this section.

As part of developing and reviewing performance dashboard reports, it is helpful to establish a useful timeframe or frequency for reporting each performance metric (6). When a performance measure experiences significant variability, it is possible that the reporting timeframe is too short or too long. High variability may indicate the influence of random short-term events (e.g., severe weather, city events, or organizational changes). Such short-term variation removes the ability to easily interpret a change and thereby lessens the value of the indicator. A moving average can compensate for such variance and help managers better identify real trends. For instance, the railcar maintenance OEE performance index introduced above provides a useful long-run measure of overall maintenance performance, so it makes sense to use a moving average to reduce the influence of short-run variance.

Performance Measures' Relationship to Department and Agency Goals

As described previously, railcar vehicle performance metrics should clearly tie to the department's and the agency's overall goals. With respect to railcar maintenance, most metrics should support three main goals: meeting the transportation operations department's needs, controlling lifecycle costs, and ensuring a high quality experience for the customer. Table 5-1 shows the relationship between department objectives and its high-level performance measures. The high-level performance measures answer key questions related to each of the overall department goals.

Table 5-1

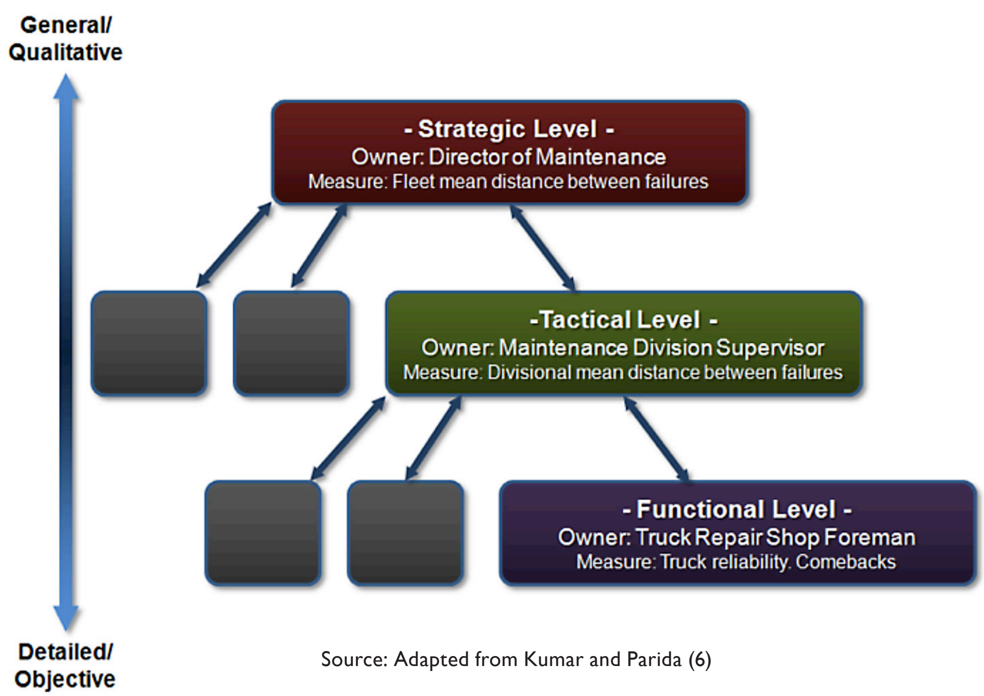
Relationship between Department Goals and Performance Factors

Performance Measure		Railcar Maintenance Department Goals	Type of Measure	Example Improvement Strategy
Availability	Percent of revenue vehicles available for peak hour service	Meeting Transportation Operations' Needs: Are there sufficient vehicle ready for revenue service?	Productivity	Improve collaboration with Inventory Management function to reduce vehicles down for parts (see Section 7, "Railcar Maintenance Facility Projects")
Reliability	Revenue fleet's mean distance between mechanical/ technical issue	Controlling Lifecycle Costs: Is preventive maintenance performed effective?	Quality/ Effectiveness	Implement or expand use of reliability centered (see Section 3, "Reliability-Centered Maintenance")
	On-time completion of scheduled maintenance	Controlling Lifecycle Costs: Is scheduled maintenance completed as planned?	Timeliness	Improve lifecycle management planning (see Section 4, "Railcar Maintenance's Role in Lifecycle Management Planning")
Maintainability	Maintenance cost per vehicle	Controlling Lifecycle Costs: Is the department successfully managing vehicle maintenance costs?	Efficiency	Enhancement of the CMMS to better track costs and improve performance management (see Section 7, "Information Technology Support")
	Preventive maintenance mean time to repair	Controlling Lifecycle Costs: Is the department repairing vehicles efficiently?	Efficiency	Use process management to continually improve work processes (see Section 3, "Pillar #1")
Condition	Vehicle condition (rating 1 through 5)	High Quality Customer Experience: Does each revenue vehicle used in service have a condition rating of at least 4?	Quality/ Effectiveness	Use quality assurance measures to reduce comebacks/improve repair quality (see Section 3, "Pillar #2)
	Customer perception of vehicle cleanliness	High Quality Customer Experience: Are revenue vehicles being kept clean for passengers?	Quality/ Effectiveness	Use quality circles to improve the ease of cleaning and address causes of dirtiness (see Section 3, "Pillar #2")
Safety	Open safety/risk issues; safety/risk issues close in last period	High Quality Customer Experience: Is the department successfully addressing potential safety issues as they arise?	Safety	System redesign/upgrade as part of a mid-life overhaul (see Section 3, "Reliability-Centered Maintenance")
	Workforce safety incidents	Controlling Lifecycle Costs: Is the department providing a safe working environment for employees?	Safety	Use mistake proofing to address safety-related human factors (see Section 3, "Pillar #1")
Financial	Adherence to budget	Controlling Lifecycle Costs: Is the department in line with its budget target?	Efficiency	Improve leadership training to enhance budget and project management skills (see Section 6, "Providing Targeted Training for Railcar Maintenance Leadership")

These high-level goals and performance measures need to translate down to consistent objectives and metrics for frontline workers. Figure 5-1 provides an example showing how the reliability-related performance measures at each level roll up into the next higher level, ensuring consistency between organizational levels and a direct relationship between detailed functional level performance measures and high-level measures for top management. At the high level, the fleet mean distance between failures metric is owned by the Director of Maintenance and might be used to understand whether there is need to invest further in Reliability-Centered Maintenance efforts, to inform an update to quality assurance processes, or to provide direction for a new vehicle procurement. At the maintenance division¬¬ level, the top vehicle system failure rates metric helps the supervisor understand which systems and functional teams are driving overall reliability fleet reliability at the division. At the level of the truck shop, the foreman can use the reliability statistics and comebacks metric to understand reliability issues related to the truck shop's work. These metrics have a clear relationship to each other and ensure that each manager is working toward the same goal. Note that it is important to update performance reports regularly to reflect changes to the organization's strategies and action plans.

Figure 5-1

Performance Management at Various Organizational Levels



Source: Adapted from Kumar and Parida (6)

Performance metrics should play a central role in the allocation of resources for performance improvement and in identifying and prioritizing investments related to railcar lifecycle management and maintenance. For example, setting and tracking a target for mean distance between failures (MDBF) directly supports the agency's overall reliability goals by tracking the frequency of in-service mechanical failures. By evaluating each project in the railcar maintenance department's draft capital projects list against key performance metrics like MDBF, it is possible to establish which projects best address the causes of in-service failures and will best support performance improvement. A similar process applies in the railcar maintenance program's budget and work planning process, for instance in the development of an annual training program.

Establishing a Performance Baseline

The maintenance program may wish to conduct a baseline assessment to better understand a maintenance program's existing strengths and weaknesses, expand on the maintenance vision, and to prioritize specific areas (e.g., computerized maintenance management system (CMMS) business processes, maintenance culture, quality assurance, equipment quality) for improvement and investment. The baseline assessment should address strategic, technical, process, administrative, and cultural issues.[27] To gather information for the assessment process, managers can use supporting management control measures such as those covered in the call-out box below. The "Key Success Factors" sections presented throughout this report provide one high-level assessment approach.

[27]The Reliability-Centered Maintenance process is one approach to develop a performance baseline and prioritize performance improvement for rolling stock.

Management Control Measures

The performance management program is one of many control measures that organizations can deploy oversee and direct operations. However, it is the most important control tool because it provides managers with critical information for decision making related to their division, department, or team's operations. Performance management uses metrics and data to monitor maintenance implementation and align the work of diverse teams with each other and the overall organization. Performance management enables managers and employees to focus on objectives and outcomes.

Other management control tools for maintenance tend to be more focused and include:

- Audits – audits may be performed by the agency's internal audit function or an outside entity. Typically audits focus on a specific aspect of operations and evaluate whether the maintenance program is using general or industry standards of practice. Quality assurance audits in particular are widely used to review the effectiveness of railcar maintenance activities.
- Budgeting – the budgeting process is the maintenance program's best opportunity to exert financial control over the maintenance process and to understand past failures in budgeting and financial control. Through the course of the fiscal year, budgets also provide an important benchmark for the maintenance program's progress and performance. The CMMS should track the budget and support comparison with actual progress and costs to help identify performance issues. Such information can feed into key financial statistics for the performance management program.
- Lifecycle management planning – lifecycle management planning is an approach to optimize asset management practices, including maintenance, over the long term. It works to integrate the decision making of all functional groups touching an asset like a railcar. Lifecycle cost analysis is the main tool behind lifecycle management planning, providing a useful model for maintenance decisions for both the overall fleet and individual vehicles.
- Statistical process control tools – these statistical approaches use the data created by maintenance, inspection, and testing activities as well as special sampling to support quality control, reliability engineering, and process improvement. Statistical techniques can help understand hidden quality issues and otherwise latent relationships to drive performance improvement, but they require focused effort and are often a way of exploring an issue identified by the performance management program.

Management Control Measures (cont.)

- Functional, system, and process diagramming – the creation of schematics which document maintenance processes and the functions of assets serves as a basis for a variety of performance improvement analyses, such as the identification of failures causes, the identification of process bottlenecks, and mapping of process costs. Such diagrams are an important way of efficiently recording information for managers, provide them a basis for comparison with observations, and help them quickly understand the likely consequences of performance issues or changes to systems or processes.
- Employee surveys and assessments – employee surveys and assessments can be helpful tool for understanding employee satisfaction and engagement, skill gaps, and other workforce issues. Low cost and free electronic services make the administration of surveys and assessment quick and efficient with output data that is easy to analyze.
- Work measurement – work measurement involves the creation of time and resource standards for jobs. Work standards benchmark the efficiency and productivity of individual workers. They also help to identify particular maintenance jobs in need improvement either through improved maintainability or better preventive measures.
- Inventory control – inventory control provides managers with insight into the vehicle maintenance supply chain and supports improved performance of the inventory and purchasing functions. Effective inventory control ensures that the correct parts are available when they are needed (1).

Communicating Performance Data

Successful performance management involves the effective communication, either formal or informal, of performance data. Ideally, performance reports are distributed automatically to managers and staff in the railcar maintenance program who are accountable for or "own" a performance measure (6). Some agencies develop dashboard reports that filter key information that is particularly relevant. For instance, Los Angeles Metro's monthly Rail Fleet Services Monthly Report selectively presents only the top reliability issues, (Figure 5-3 excerpts the reliability data from the report), so that the manager only sees the most actionable information in detail (7).

If frontline workers do not receive performance reports directly, managers can share relevant performance data on a regular basis. Communication of performance results provides an opportunity to discuss performance expectations, operational consequences of not meeting targets, and opportunities for improvement. It can help focus and motivate employees, especially on short-term goals (8), (9). Performance measurement should not be used punitively. When issues are identified, it is important to share responsibility for fixing them and facilitate and support teams that are not effective and cannot meet their goals. Strategies for addressing performance issues are presented in detail in Section 3 (3).

Frontline employees can provide critical input to the performance management program. They usually have a keen understanding of how they can influence and even manipulate performance measures and how well the performance measures actually provide an understanding of their work and value. Employees' involvement and input into the development of a new performance measurement program may also be important to get their buy-in. Employees are more likely to resist change when they have not had a voice in the process. Ongoing communication in both directions helps to set expectations and determine targets (3).

Common Pitfalls in Performance Reports

- Data overload: too much data makes it difficult for the audience to hone in on the critical issues. Unnecessary metrics should not clutter the performance report.
- Insufficient detail: very high level summary performance data can make it difficult to draw meaningful conclusions. The level of detail needs to correspond to the organizational level of the audience. More granular data are more actionable for frontline employees.
- Use of the data: performance data should arrive at useful intervals to support decisions. Managers should use the data to determine action items and to evaluate their business plans and decisions.
- Performance measures should link directly with the agency's stated goals instead of conflicting with them or having no relationship at all.
- Progress should be measured at useful intervals to reflect the rate at which trends appear and the timing of decisions.
- It is important to focus on the customer above all else, since it is the customer who determines the agency's success (3).

As a final point, it is possible to have too much focus on the performance measurement system itself. The system should be comprehensive and provide data at an appropriate level for its audience. However, it remains just a tool. So long as it covers important areas and is reasonably accurate, it can serve its purpose. Most of the work takes place in the actual investigation of reasons behind performance trends. The performance measurement system should be regularly reviewed and updated if necessary at a reasonable interval (3).

Data Collection and Quality Assurance

The data on which performance indicators are based require collection, analysis, and transmission to the appropriate staff. Ideally, data collection is automated through information systems; however, in most railcar maintenance departments, at least part of the data process is manual. In either case, it is important to carefully document and oversee the data collection process to ensure the transparency of data sources and the quality and integrity of data incorporated in the railcar maintenance performance management program.

Data Collection

To the extent possible, performance data should be collected through the transit agency's various information systems carrying. These systems can include the computerized maintenance management system (CMMS), the enterprise resource planning (ERP) system, and any other related systems, as shown in Table 5-2. The CMMS (discussed in more detail in Section 7, "Railcar Maintenance Facility Projects") is the railcar maintenance manager's critical information system, automating data collection to support the detailed documentation and analysis of work completed and comparison against the department's goals. Maintenance workers log their work as they complete standard tasks, including inspection and testing, standard preventive maintenance procedures, and repairs. The result is a detailed record of the maintenance work performed (2).

Table 5-2

Typical Data Sources for Monitoring Railcar Maintenance Activities

Railcar Maintenance Activities and Resources	Typical Data Source
Work order and labor records	Computerized Maintenance Management System
Materials and parts inventory and use	Computerized Maintenance Management System
Maintenance tools and equipment tracking	Computerized Maintenance Management System
Facilities and infrastructure	Computerized Maintenance Management System
Plans, procedures, and other documentation	Computerized Maintenance Management System
Inspections and testing	Computerized Maintenance Management System
Personnel with the appropriate skill set	Enterprise Resource Planning System
External resources (contractors, etc.)	Enterprise Resource Planning System
Training	Enterprise Resource Planning System
Budgets and accounting	Enterprise Resource Planning System
Engineering reports	Product Lifecycle Management System
Operations data	Operations Control Center/Computer-Aided Dispatch System; vehicle onboard computer
Online condition monitoring and diagnostics	Vehicle onboard computer

The CMMS and ERP can gather enormous quantities of data, and, when querying these systems' databases, it is often possible to calculate a given performance measure multiple ways. Managers should make sure they clearly understand the performance measures' calculation and that this information is easily available to those using the performance reports (6).

Not all performance data are collected through automated business processes. The performance management program may include summary results from ongoing quality assurance audits of vehicle preventive maintenance or regular employee satisfaction surveys. In such cases, the performance management program should include supporting documentation for these measuring processes. Clear instructions for what measurements are taken, the frequency of measurements, and the analysis required for the measurements gathered ensure consistency in data collection over time. If possible, maintenance workers should record key data collected in inspection reports in the CMMS or a related system (8).

Quality Assurance

It is critical to the integrity of the performance measurement program that there is a coherent and comprehensive QA/QC program in place to monitor and identify any data issues. The need for such a program holds true, in particular, for large maintenance organizations where upper level managers have more limited insight into daily operations from their personal observations. Common quality assurance approaches for performance data include:

1. Job sampling – As part of quality assurance staff's random checks of vehicle inspections and maintenance jobs, they should verify accurate entry of data into the CMMS. Job sampling rates are often fairly high: up to 20 percent is a good rule of thumb for major preventive maintenance tasks, so a high level of data quality is assured. Quality assurance audits (see Section 4, "Maintenance Quality Assurance") provide a similar ongoing opportunity to verify the quality of the data being entered into information systems.
2. Certification program – A quality assurance checklist is created for each procedure to check quality and functionality at key steps. Each test check or test should have a clear objective outcome or standard to pass. Instituting these validation steps through the CMMS helps ensure the checks are completed and tracked.
3. Issue follow-up – As data errors are identified it is important to follow-up to understand the causes of the errors and put in place corrective measures such as training or new data validation processes.

Disciplined adherence to protocols ensures the quality of data collected through the CMMS and its effectiveness as a management control measure (10), (11).

Utilizing Performance Measures to Support Management Decisions

Even with a high quality performance measurement system in place, managers need effective processes to translate the information into decision-making and action. This section discusses how best to apply performance measures to support the accomplishment of rail car maintenance objectives.

Performance Targets/Benchmarking

A railcar maintenance program needs standards or targets that correspond to each performance indicator to ensure the effectiveness of the performance management program. A performance target provides a point of comparison to help understand the agency's success in the area being measured. The standard or target should reflect an objective judgment of the performance threshold at which the agency can reasonably be said to have accomplished its stated objective.

Maintenance performance standards and targets can be developed based on internal or external benchmarks. Internally, standards and targets may involve comparison with other teams, divisions, and departments, or involve development of an objective standard, such as a time standard. External standards and targets, on the other hand, can be established against other transit agencies and organizations in related industries (8), (4). When benchmarking externally, it makes sense to focus on directly comparable areas within a relevant set of peers. Examples areas of railcar maintenance that make sense to benchmark externally include: inventory management, vehicle availability, workforce injuries, and customer satisfaction. Peer industries might include utilities, mining operations, airlines, and military operations. The focus of benchmarks should be on world class performance standards to give a realistic perspective on the agency's actual performance and room for potential improvements. Railcar maintenance managers should avoid using arbitrary performance targets that do not correspond to a reasonable definition of success (10).

Transit Benchmarking: Nova and Community of Metros

Benchmarking is an important tool for transit agencies to measure their performance using an objective point of comparison. Montreal's public transit agency, the Société de transport de Montréal (STM), sought out to improve its transit performance by benchmarking its performance with peer agencies from around the world by participating in Nova. Nova (for agencies with less than 500m trips/year) and Community of Metros (CoMET, for agencies with more than 500m trips/year) are two international transit rail benchmarking groups that collaborate through sharing performance data and best practices. Both groups provide a forum for agencies from around the world to share experiences and learn from each other, with a focus on performance improvement and strategies that are transferrable.

The benchmarking process used by Nova and CoMET includes a key performance indicators system to compare performance and identify best practices and a web platform for sharing case studies, giving workshops, and providing an online forum for knowledge sharing. The group is under a strict confidentiality agreement that allows agencies to practice full disclosure with each other. The groups serve as forums to identify opportunities for cost-savings and improved efficiency and also to understand industry trends and better define performance. The groups have also spurred agencies to develop more comparable data and address some of the inconsistencies in performance reporting across the industry.

In STM's case, the agency was able to use its membership in Nova to better understand its strengths and weaknesses and identify key areas for improvement. The agency has emphasized the use of performance management at all levels, and benchmarking was an important exercise to ensure the agency had a realistic understanding of its baseline performance and that upper managers had realistic overall expectations. The benchmarking initiative showed that while STM had a very high average fleet age and lower than average training levels, the agency was maintaining above average reliability. The agency was also setting a world class standard for labor productivity in operations and maintenance (16).

Labor efficiency is a key concern in railcar maintenance, and time standards are a common type of performance standard to provide an objective benchmark of efficiency. Typically, a time standard not only specifies an expected duration for each step in the maintenance task; it also sets forth the resources required for the task, as well as precise, standardized steps to complete it. Time standards can serve as building blocks for most maintenance management and budgeting systems because they enable work planning and resourcing work. They help managers better understand the equipment and labor requirements for preventive maintenance, running rehabilitations, and common repairs and provide a basis for financial planning and ongoing performance measurement. The development of a time standard for a common maintenance task can also help improve maintenance quality and efficiency by creating explicit maintenance procedures for workers to follow (see the time standard development approach described in the call-out box below) (11).

Time standards are most appropriate for tasks that maintenance workers perform regularly and that have a predictable work process. They require diligent time accounting on work orders through the CMMS. Where actual times exceed the standard significantly, the manager can check whether the mechanic identified deficiencies to address or the CMMS maintenance records provide some other explanation. In this way, the standard provides some accountability to maintenance staff to encourage productivity and helps managers to identify individual issues such as lack of training or deviation from preventive maintenance procedures (12). Manpower ratios are a related productivity standard for benchmarking staffing levels at the organizational rather than the task level. They measure the staffing of a particular position in full time equivalents against a standard unit such as a vehicle or 100,000 revenue miles and are useful for comparing productivity across maintenance divisions or with other transit agency's railcar maintenance departments (13).

The use of time standards as a management tool is evolving. Rather than focusing too heavily on standard repair times and other productivity standards, managers are increasingly focusing on quality, effectiveness, and overall program efficiency measures. For instance, "comebacks" are a critical indicator of maintenance effectiveness that managers can track to individual employees. The adoption of approaches such as total productive maintenance (see Section 3, "Total Productive Management") that rely on the initiative of frontline staff to identify and address issues and confer a high degree of flexibility on frontline staff can be at odds with the prescriptiveness of time standards. Moreover, employees are understandably resistant to the use of time standards as an enforceable productivity standard (9). Still, time standards continue to be useful for planning and budgeting and for establishing discipline among frontline workers in their maintenance practices.

Development of Vehicle Maintenance Time Standards

The development of a time standard is an opportunity to reengineer the procedure to eliminate delays, reduce transport times, and minimize storage time. The development of a time standard begins with a process mapping of the maintenance procedure. To understand inefficiencies in the procedure, the review team can apply five categories of time uses to a process map of the maintenance procedure (see Section 3, "Pillar #1," for more on process mapping): (1) operation: performance of the actual maintenance procedure, (2) transport: time spent moving the vehicle or system into place or traveling to retrieve a tool or part, (3) inspections: examination of the system to assess condition, performance, or work quality, (4) delays: time wasted due to interruptions or unforeseen obstacles such as a missing part or non-functioning equipment, and (5) Storage: inactive time where the vehicle, system, part, or worker queues for the next activity, extending the time unavailable and reducing productivity. Once each process step is assigned to a time category and its average duration is measured, a summary table shows the total time needed in each category and provides a basis for directing performance improvements to the procedure. Examples of improvements from mapping a maintenance procedure and establishing a time standard include:

- Analysis of the process may reveal redundant activities such as multiple set up periods which could be eliminated by dedicating a bay for several successive shifts or creating a temporary work station. A dedicate work station ensures all necessary tools are on hand and that maintenance is conducted with appropriate ergonomics.
- Conducting all the work in a single location can reduce transport costs.
- Providing a parts kit or bill of materials for the procedure can reduce overall transport time. Transport time often leads to delay from behavior such as stopping to chat with colleagues.
- Sequential workflow can help reduce redundant activities that result from working on task elements in parallel.
- For maintenance procedures involving multiple mechanics, accounting for inactive (or "storage") time for each worker can help identify opportunities to shift responsibilities or the order of tasks to better balance the work among team members and improve productivity.

An effective time standard relies on actual time readings from a normal and reasonable work pace. When targeting inefficiencies related to workers' habits, the focus should be on specific procedure updates. For instance, improving set up and breakdown procedures can improve organization and reduce sporadic trips to retrieve tools and equipment. The development of standard repair

Development of Vehicle Maintenance Time Standards (cont.)

times should undertaken by a credible party with expert knowledge of the maintenance procedure. Senior mechanics with quality control responsibilities can be a good choice. Together with a performance analyst if necessary, they can effectively break down the maintenance procedure into discrete tasks and note key differences among mechanics and setups (11). When establishing a time standard, it is important to rely on the best-performing mechanics, technicians, and shops to ensure the standard's high quality (9).

New York City Transit has successfully used time standards as a performance improvement process involving the development, review, standardization, and update of maintenance procedures and documentation. The agency's review process emphasized the collaboration of the unions and made use of process mapping and re-engineering to adjust the scope, bill of materials, tools, documentation, and procedures for the repair. After finalization and approval of the standard, the updates would be reflected in the system of record, the change communicated to maintenance staff, and additional training given as necessary. Once the new standard repair time had been implemented, a performance incentive applied to employees who consistently met the standard (9), (17).

Decision Process

The primary purpose of performance indicators is to provide line-of-sight for managers into maintenance operations. When performance indicators indicate a performance issue, they must also support decision-making to identify the appropriate response of the department's management and staff. For each performance indicator, the options to address the performance issue can vary significantly. In some cases, maintenance workers can apply swift corrective action to address the issue. Other cases may require concerted long-term attention with an action plan involving multiple supporting actions. Furthermore, some actions are only feasible during discrete windows of opportunity. For instance, a particular reliability issue may only be cost-effective to address as part of a major rehabilitation program that takes vehicles out of service and require significant planning and coordination.

Nevertheless, the maintenance staff member responsible for each performance measure should have a clear understanding of his or her responsibility for follow-up action. The decision tree in Figure 5-2 provides an example of how the railcar maintenance department's truck shop might respond to a drop in its reliability measure. The underlined responses show the decision logic that applies.

Figure 5-2

Sample Decision Logic Applied to Monitoring Key Performance Indicators

Is the performance target being met?		
The Truck Shop has set a reliability target of 100,000 miles between failures.		
Yes		
1.	Does the current reliability target reasonably define success?	
	Yes	
	1.1	No action required; continue to monitor.
	No	
	1.2	Revise the performance target. Proceed to 2.
No	*Over the last three months, the Truck Shop's reliability has slipped to 80,000 miles between failures.*	
2.	Is the reliability issue high priority relative to other current performance issues?	
	Yes	*Because of the cost and service quality impacts, the Truck Shop has made the reliability issue a priority.*
	2.1	Address truck shop reliability performance immediately.
		Step 1: Identify root causes of the performance issue.
		Is poor truck reliability related to parts? Procedures? Workforce?
		Step 2: Convene key stakeholders to address the performance issue.
		Truck shop mechanics, a supporting vehicle engineer, a representative from purchasing
		Step 3: Identify potential improvement strategies.
		Maintenance procedures (see *Section 3*) - *conduct an RCM project in the Truck Shop.*
		Planning issue (see *Section 4*) - *improve planning of the Truck Shop's preventive maintenance to ensure planned work better supports equipment reliability.*
		Performance management issue (see *Section 5*) - *implement more detailed performance monitoring to better understand the performance issues and support Truck Shop quality assurance efforts.*
		Workforce management issue (see *Section 6*) - *implement new trainings to improve the Truck Shop staff's quality assurance knowledge and practices.*
		CMMS, Inventory Management, or Procurement issue (see *Section 7*) - *improve quality of data collected in the CMMS; improve parts procurement to test and select parts for higher quality.*
		Step 4: Implement the promising performance improvement strategies.
		Step 5: Continue monitoring.
	No	
	2.2	Defer action until resources are available.

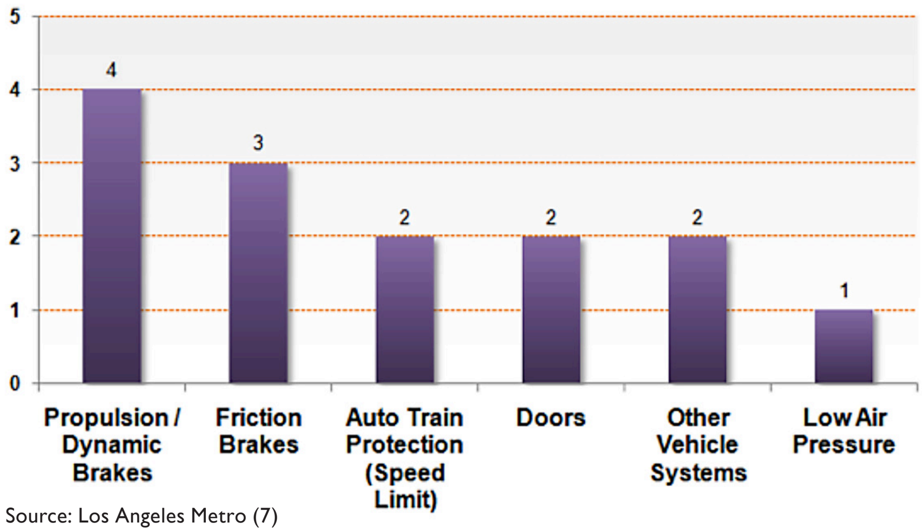
Performance Improvement and Accountability

As part of the performance measurement program, all goals and associated performance measures should be tied to a specific individual in the railcar maintenance program. This responsible individual is usually the manager or other staff member with the greatest control over the process that the performance measure monitors. In general, senior management focuses on strategic measures, middle management on operational measures, and junior management and other staff on staff individual measures. Senior managers are responsible for ensuring the staff under their supervision is held accountable for performance results, including explaining and addressing performance issues. Senior managers need to use performance measurement to proactively identify and follow up on performance issues, to underwrite decision making, and to hold lower managers and workers accountable (6). Accountability helps the railcar maintenance organization project its leaders' vision and planning down to all frontline workers. The line-of-sight associated with each performance measure needs to correspond to the maintenance department's organizational and accountability structure. As discussed earlier, line-of-sight ensures oversight in each area so that responsibility flows up through the organization (3).

Managers at various levels rely on performance reports to inform both daily and longer-term decision-making. Performance reports should have a scope appropriate to the recipient's roles and responsibilities: detailed performance measures for the recipient's areas of direct responsibility and impact and then more high-level measures for relevant areas where the report recipient has only indirect (but significant) impact. For example, the Director of Railcar Maintenance is responsible for the overall reliability of the railcar fleet; therefore, the Director is accountable for meeting the mean distance between failures measure target. Likewise, if a particular team services railcar doors, the shop's foreman would be responsible for the shop's overall effectiveness and for the failure rate shown in Figure 5-3. For repeat failures, shown in Figure 5-4,[28] a particular mechanic or team may be held accountable for any given comeback and required to undergo special training or institute additional quality assurance checks until the issue is resolved.

Figure 5-3

Los Angeles Metro Rail – Top Incident Categories, March 2012



Source: Los Angeles Metro (7)

[28]Figure 5-3 and Figure 5-4 are illustrative examples excerpted from Los Angeles Metro's *Rail Fleet Services Monthly Report.*

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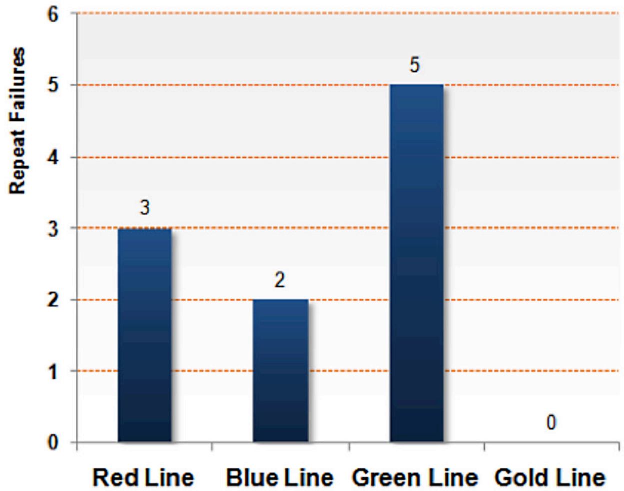
Figure 5-4

Los Angeles Metro Rail – Repeat Failures, March 2012



System	Metro Rail Line	Car	Repeats
ATO	Red Line	571	1
Propulsion / Dynamic Brakes	Blue Line	248	1
	Red Line	523	1
	Green Line	215	1
	Green Line	226	1
	Green Line	228	1
Radio	Blue Line	138	1
	Red Line	537	1
	Green Line	216	2

Source: Los Angeles Metro (7)

Because railcar maintenance staff records most or all work in the CMMS, the department has access to detailed performance data at the level of the individual worker, vehicle, and vehicle system. Such data support targeted performance feedback to railcar maintenance workers at all levels. The inclusion of broad performance measures in performance reports can provide recipients with information to contextualize their own performance and responsibilities and better understand the current challenges and focuses of the both the overall maintenance program and the agency as a whole.

Merely collecting and disseminating performance data is not sufficient for the development of alternatives to improve maintenance practices. Performance measures must convey sufficient information to managers about negative trends to suggest reasonable next-step actions. Analysts supporting the maintenance department can help ensure the development of a comprehensive and actionable performance measurement system. The same analyst skill set is also valuable to support ongoing performance monitoring with data-driven diagnostics and optimization of maintenance strategy and processes (14).

Key Success Factors

- Performance measures have clear line of sight to agency goals.
- Performance measures cover all critical department activities and responsibilities.
- Performance measures provide timely and actionable information.
- Specific individuals have ownership of each performance measure and any follow-up actions.
- The department keeps digital records of all data in a single system of record.
- The department emphasizes the automated collection of data, for instance, through work orders in the computerized maintenance management system.
- Benchmarks and performance targets reflect a reasonable definition of success for each activity measured.
- Performance measures are effectively communicated and follow-up actions have clear ownership.
- The performance measures are periodically reviewed and updated to reflect changes in operations and performance monitoring needs.

Table 5-3

Example Railcar Maintenance Performance Measures

Railcar Maintenance Function	Performance Measure	Description
Maintenance Implementation - General	Fleet Availability	Percentage of vehicles available for peak revenue service
Maintenance Implementation - General	Fleet Reliability	Mechanical failure/vehicle breakdown rate or interval (miles or hours)
Maintenance Implementation - General	Overall Equipment Effectiveness	Performance index combing availability, productivity, and quality
Maintenance Implementation - Availability	Spare Ratio	Number of spare vehicles as a percentage of total fleet
Maintenance Implementation - Availability	Vehicle Condition	Percentage of vehicles not fit for revenue service; reason for each vehicle
Maintenance Implementation - Maintainability/Cost	Accounting Accuracy - Work Orders	Total costs charged to assets vs. total maintenance costs
Maintenance Implementation - Maintainability/Cost	Continuous Improvement	Savings from RCM/quality improvement team/ kaisen projects
Maintenance Implementation - Maintainability/Cost	Equipment Availability	Availability percentage for key maintenance equipment
Maintenance Implementation - Maintainability/Cost	High Priority/Emergency Work Orders	Percentage of work orders which are high priority

Table 5-3 (cont.)

Example Railcar Maintenance Performance Measures

Railcar Maintenance Function	Performance Measure	Description
Maintenance Implementation - Maintainability/Cost	Labor Intensity	Full-time equivalents per vehicle
Maintenance Implementation - Maintainability/Cost	Maintenance Backlog	Number of work orders/issues outstanding or overdue
Maintenance Implementation - Maintainability/Cost	Maintenance Backlog	Number of work orders open over X days
Maintenance Implementation - Maintainability/Cost	Maintenance Capacity Utilization	Percent of maintenance capacity in use
Maintenance Implementation - Maintainability/Cost	Maintenance Efficiency	Maintenance cost/labor hours per vehicle service hour
Maintenance Implementation - Maintainability/Cost	Maintenance Intensity	Maintenance cost/ asset replacement value
Maintenance Implementation - Maintainability/Cost	Overtime Efficiency	Labor overtime as a percentage of total labor hours
Maintenance Implementation - Maintainability/Cost	PM/repair Efficiency	Mean cost/mean labor hours/mean time of a standard job
Maintenance Implementation - Maintainability/Cost	Preventive Maintenance Efficiency	Actual PM time/planned PM time
Maintenance Implementation - Maintainability/Cost	Process Management	Number of maintenance department processes with process managers
Maintenance Implementation - Maintainability/Cost	Rehabilitation Program	Summary of rehabilitation activities completed/ overall progress/schedule adherence
Maintenance Implementation - Maintainability/Cost	Response Time	Mean time from corrective issue reported to repair beginning
Maintenance Implementation - Maintainability/Cost	Warranty Recovery	Percentage of maintenance jobs completed under warranty agreement
Maintenance Implementation - Maintainability/Cost	Warranty Recovery	Percentage over materials costs recovered under warranty agreement
Maintenance Implementation - Maintainability/Cost	Work Order Closeout	Average time work orders open
Maintenance Implementation - Maintainability/Cost	Work Order Turnover	Work orders closed per day/total work orders open
Maintenance Implementation - Reliability	Corrective Maintenance Workload	Percentage of total maintenance cost due to corrective maintenance
Maintenance Implementation - Reliability	Corrective Maintenance Workload	Percentage of total corrective maintenance work orders
Maintenance Implementation - Reliability	Engineering Backlog	Summary of projects in progress/summary of project backlog and prioritization
Maintenance Implementation - Reliability	Failure Follow-Up	Percentage of in-service mechanical failures where failure analysis was performed
Maintenance Implementation - Reliability	Operator-Identified Defects	Number of defects identified by operators per run, 100,000 train miles, etc.
Maintenance Implementation - Reliability	PMI Follow-Up	Percentage of total work orders generated as part of inspections
Maintenance Implementation - Reliability	Predictive Maintenance Use	Percentage of work orders or PM hours dedicated to predictive maintenance
Maintenance Implementation - Reliability	Preventable Failures	Percentage of in-service mechanical failures that were preventable

Table 5-3 (cont.)

Example Railcar Maintenance Performance Measures

Railcar Maintenance Function	Performance Measure	Description
Maintenance Implementation - Reliability	Quality Assurance Audit	Percentage of work orders audited
Maintenance Implementation - Reliability	Rebuild Effectiveness	Mean number of rebuilds to failure
Maintenance Implementation - Reliability	Repair Effectiveness	Mean time to failure of system/component after repair
Maintenance Implementation - Reliability	Repeat Maintenance/ Comebacks	Number of repeat jobs as a percentage of total jobs or per thousand work orders
Maintenance Implementation - Reliability	Repetitive Failures	Number of repetitive failures vs. total failures
Maintenance Implementation - Reliability	Vehicle Condition	Mean condition rating
Maintenance Implementation - Reliability	Vehicle/System/Component Reliability	Mechanical failure/vehicle breakdown rate or interval (miles or hours)
Maintenance Implementation - Safety	Vehicle Safety	Number of vehicle accidents/safety incidents; summary of each incident
Maintenance Implementation - Safety	Worker Safety	Number of safety incidents/worker injuries/ near misses
Maintenance Implementation - Service Quality	Cleanliness	Number of vehicles overdue for general cleaning
Maintenance Implementation - Service Quality	Cleanliness	Average number of days between general cleaning
Maintenance Implementation - Service Quality	Cleanliness	Level of vehicle cleanliness (customer survey)
Maintenance Implementation - Service Quality	Customer Complaints	Number of maintenance-/condition-related customer complaints
Maintenance Implementation - Service Quality	Customer Impact of Failures	Total delay experienced by customers attributed to mechanical failure (estimate or customer survey)
Maintenance Implementation - Service Quality	Customer Impact of Failures	Average length of customer delay attributed to mechanical failure (estimate or customer survey)
Maintenance Implementation - Service Quality	Failure Impact	Direct and indirect costs of in-service failures
Maintenance Implementation - Sustainability	Energy Consumption	Energy use
Maintenance Implementation - Sustainability	Environmental Incidents	Number of environmental incidents/violations
Maintenance Implementation - Sustainability	Waste Production	Total waste production
Maintenance Implementation - Sustainability	Water Consumption	Volume of water use
Planning	Budget Adherence	Department's and teams' spending remains in line with their budgets
Planning	Work Planning	Annual work plan created on schedule
Workforce	Attendance	Absenteeism rate
Workforce	Critical Skills	Number of employees with specific critical skills
Workforce	Critical Trainings	Percentage of employees meeting core/critical training requirements; summary of trainings administered

Table 5-3 (cont.)

Example Railcar Maintenance Performance Measures

Railcar Maintenance Function	Performance Measure	Description
Workforce	Discipline	Number of work rules violations
Workforce	Labor Cost	Average burdened labor rate by class
Workforce	Labor effectiveness	Railcar downtime per maintenance employee
Workforce	Labor productivity	Mean number of work orders per frontline maintenance employee
Workforce	Training	Training hours per employee
Workforce	Training Need	Percentage of comebacks due to lack of training
Workforce	Turnover Rate	Employee turnover rate for critical workers
Vehicle Procurement	Schedule Adherence	Progress against/adherence to planned program schedule
Vehicle Procurement	Budget Adherence	Progress against/adherence to planned program budget
Inventory Management	Accounting Accuracy - Parts	Percentage of parts costs/items charged to assets
Inventory Management	Expedited Shipping	Total Expedited Shipping Costs
Inventory Management	Inventory Accuracy	Percent of inventory items with accurate balances
Inventory Management	Inventory Accuracy	Value of variances as a percent of total inventory value
Inventory Management	Inventory Currency	Percentage of inventory items that are inactive
Inventory Management	Inventory Efficiency	Months of inventory on-hand
Inventory Management	Inventory Order Fulfillment	Percentage of requisitions filled on demand
Inventory Management	Inventory Order Fulfillment - Back-Orders	Mean number of days to fill a back-order
Inventory Management	Inventory Service	Number of part returns due to wrong part supplied
Inventory Management	Inventory Turnover	Value of inventory issued/total inventory on hand
Inventory Management	Inventory Value	Inventory value per vehicle
Inventory Management	Inventory Workload	Number inventory transactions per person
Inventory Management	Out-of-Stock Items	Total number of active items out of stock
Inventory Management	Out-of-Stock Items	Mean time out of stock
Inventory Management	Stock-Outs	Number of stock-outs as a percentage of total requisitions or per thousand reqs
Inventory Management	Vehicles Down Due to Parts	Number of vehicles out of operation waiting for parts
CMMS	CMMS Efficiency	Average time per transaction
CMMS	CMMS Integrity	CMMS data entry error rate (data quality control audits)
CMMS	CMMS Reliability	Percentage of time CMMS is unavailable due to technical problems

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SECTION

6

Workforce Training and Organizational Development

This section discusses challenges related to management of the railcar maintenance workforce and strategies and opportunities for improving workforce skills and performance. It discusses state of the practice around training, knowledge management, and creating a maintenance culture focused on productivity and quality.

Employees must have the appropriate skills and knowledge to perform maintenance tasks efficiently and accurately, ensure ongoing quality of maintenance work, meet changing maintenance needs and support performance improvement processes. Workforce training and development is critical for successful maintenance management due to:

- The introduction of emerging technologies into organizations that require new skills and staff training
- Workforce transitions and employee turnover putting agencies at risk of losing institutional knowledge and competencies
- The recognition of the need for interpersonal, collaboration, and problem solving skills at all levels to support a learning organization

Workforce training and development is central to Total Productive Maintenance's fourth pillar—Continuous Learning (addressed in Section 3, "Pillar #4" and expanded on in this section)—and can improve maintenance operations by raising employee satisfaction and reducing turnover rates, improving maintenance efficiency and effectiveness, and reducing safety risk to personnel. The active participation of the maintenance workforce, including its commitment to a customer- and quality-focused vision, is a necessary foundation to fleet management improvement efforts (1), (2), (3). This section covers key issues in workforce training and organization development, including how to identify specific skill gaps and target training resources, how to address skill gaps when implementing new fleet and maintenance technologies, how to prevent the loss of institutional knowledge, and how to support a positive work culture in maintenance.

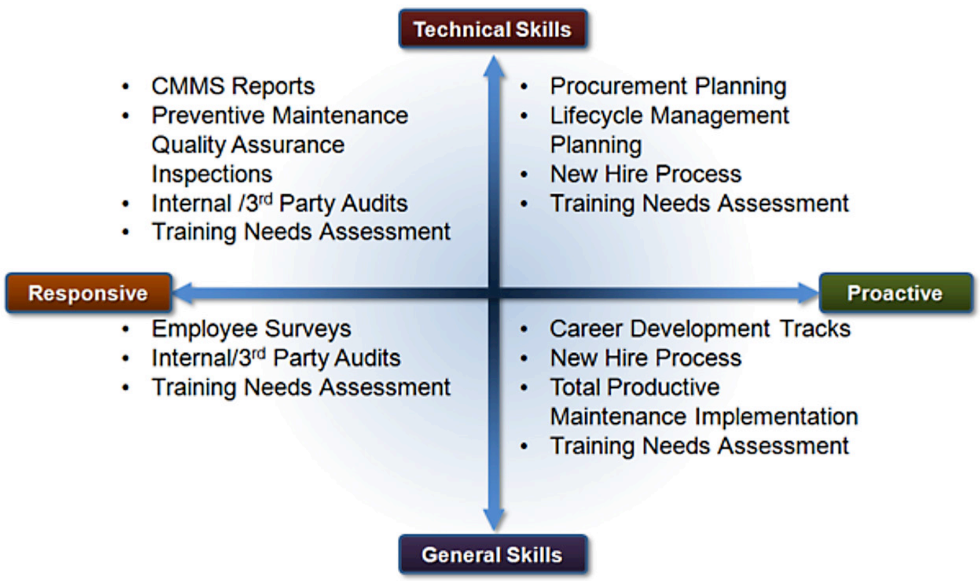
Addressing Skill Gaps

Employee skills need to closely match the work planned to carry out the agency's railcar maintenance goals. In many cases, managers can use forward looking assessments to identify and proactively address skill gaps before they impact maintenance operations, for instance, as part of procurement planning for a new vehicle purchase. More often, managers must rely on performance data and retrospective performance assessment to identify skill gaps in the maintenance workforce that are impacting operational performance.

Training can address two types of skills: technical skills for fleet maintenance and repair and general skills such as problem solving and teamwork to support the technical skills. Improving these two types of skills can improve maintenance and repair efficiency and reduce the time it takes to return a vehicle to service (4). Figure 6-1 shows common processes for proactive and responsive identification of training needs for both types of skills.

Figure 6-1

Identification of Training Needs



This section outlines the approach to identify skill gaps and addressing them through targeted, cost-effective trainings. It also discusses how to make the case for additional funding for training.

Identifying a Skill Gap

Of the processes listed in Figure 6-1, three are general approaches that can be used regularly at managers' discretion to identify skill gaps of the fleet maintenance workforce:

1. Skills audit
2. Training needs assessment
3. Analysis of maintenance management system reports/data

These three options are discussed in more detail below.

Skills Audit

Regularly assessing the existing workforce skill set can help agencies determine where skill deficiencies exist, how they evolve over time, and which types of trainings best suit agency needs. A skills audit can be incorporated as part of employees' annual performance review, and the results of the skills audit can be used to create a training profile that maps out employees' current skill levels, where they should be or want to be, and what trainings they need to take to attain an appropriate skill level or to reach their career development goals. The training profile helps to facilitate targeted training for those who need it the most and provides a constructive rather than disciplinary framework to address skill deficiencies.

The most common form of a skills audit is a questionnaire that can be administered by managers and supervisors, who can meet with their direct reports to fill it out together (5). The skills audit establishes the employee's job description, typical duties and tasks performed, skills and knowledge required for each task, equipment used for the position, any skills that are currently lacking, and previous training history.[29] The questionnaire results can also be supplemented with interviews, written or skills tests, and workplace observation. The final skill requirements are then compared against the actual skill sets of the workforce to understand the gap areas. For example, as part of a skills audit, managers might conduct a test of electronics shop workers' proper use of bench test equipment for diagnostics. The test would verify whether employees followed test procedures accurately, knew how to use bench test equipment properly, and knew how to correctly diagnose particular issues. The Southeastern Pennsylvania Transportation Authority conducted a skills audit to prepare for the delivery of the agency's latest generation of railcars, Silverliner V, to ensure the fleet maintenance workforce was prepared to maintain a new generation of vehicles (6).

A skills audit is not only intended to measure the adequacy of employees' technical skills but also to assess general skills, such as math and literacy aptitude. Often, the underlying reason for poor performance of a maintenance task is not a lack of mechanical aptitude, but actually weak mathematics or literacy skills or an inadequate overall conceptual understanding of the task. A deficit of foundational skills and knowledge can cause problems later as workers advance to carry out more complicated and technical tasks (5).

Training Needs Assessment

A training needs assessment is another approach to understand and address a perceived skill gap. It is more focused than a skills audit which would cover

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[29]The APTA Rail Vehicles Maintenance Training Standards, which were developed to address the shortage of skills resulting from changing technologies and shifting workforce demographics, can be used as a guide to possible topics to cover within a skills audit. For the full document, see http://www.aptastandards.com/Portals/0/Rail/MaintTrain/vehicles.pdf.

the railcar maintenance program generally. A training needs assessment might be used to further investigate specific critical areas identified as problematic in a skills audit. However, it is not so specific as target just a single technical procedure. The training needs assessment represents a methodical process to understand training needs and develop cost-effective training strategies. The process consists of seven core steps carried out by an assessment team[30] to understand the problem and implement appropriate responsive training:

1. **Clarify the need**. Performance reports or management input may identify a performance issue indicating a possible training need, but to verify the need and formulate a training approach, it is necessary to target specific performance issues. The assessment team should document the core performance issue and validate their ideas with management and staff. Areas to document would be the employees or positions involved, the processes or procedures behind or related to the need, the impact of the issue and its criticality, and the benefits of addressing the need.
2. **Understand the performance gap**. The next step is to understand the performance requirements surrounding the core performance issue and the extent to which employees are failing to fulfill these requirements. At this step, it should be clear whether training is an appropriate strategy to address the core issue, as well as what the appropriate level of effort is for the training needs assessment.
3. **Formulate questions and goals**. It is important to carefully formulate the questions the training needs assessment is seeking to answer and set specific goals for the process. Common questions to answer include:
   - Who should undergo the training?
   - When should they undergo the training?
   - What should be the scope of the training?
   - How should the training be developed?
   - What types of training might be appropriate?
   - Who should carry it out?
   - What are the expected outcomes of the training?
   - How should training outcomes be measured?

4. **Plan the analysis**. In this step, the assessment team lays out how to meet the assessment goals. The project plan should cover what analysis is appropriate, what data are necessary to support the analysis, what stakeholders should be included, and who the ultimate decision makers should be. Common data collection approaches include observation, interviews, CMMS data analysis, surveys, and supplemental self-reporting by key employees.

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[30] Note that an assessment team may be structured and managed the same as a quality improvement team; see Section 3, "Quality Improvement Teams."

5. **Implement the plan.** The data collection and analysis should result in a firm and detailed set of requirements for a proposed training program.
6. **Review the outcomes**. Once the assessment team has compiled the project findings and recommendations, they should be circulated to stakeholders and decision makers for review and comment.
7. **Implement the training program.** Once the proposed training program is refined and approved, the resources identified for the program's development must begin implementation of the program. The assessment team members typically continue to support the project (7).

Analysis of Maintenance Management Data

Another way for managers to identify training needs is through standard computerized maintenance management system (CMMS) reports, such as comebacks and issues flagged in quality assurance inspections of maintenance jobs. Specific recurring mechanical issues or differences among individuals, teams, and locations can all indicate a training issue. Special-purpose data collection, such as employee surveys and time standard development,[31] is another option for characterizing training needs. Finally, senior mechanics, foremen, and supervisors may also identify training needs through their observations on the shop floor.

Managers may also proactively identify training needs through various planning processes. New vehicles and technologies, facilities and equipment, processes and approaches, or organizational structures may all require some level of training for successful implementation, which should be included in project planning. The annual budgeting process and the development and update of vehicle lifecycle management plans[32] are also opportunities to identify needs for proactive training. Finally, railcar maintenance programs can benefit from workforce planning, including the identification of training needed to support standard career development tracks (8).

Selecting the Appropriate Training and Approach

Training ensures workers have the knowledge, skills, behaviors, and attitudes necessary to effectively carry out their maintenance responsibilities and, ideally, address any identified skill gaps. Training may be responsive and address ongoing or emerging performance issues or be proactive and prepare the workforce for anticipated events such as the implementation of Reliability-Centered Maintenance, a new railcar procurement, an upgrade to the CMMS, or the retirement of key technical staff (5).

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[31]See Section 5, "Performance Targets/Benchmarking."

[32]Such as the agency's fleet management plan or vehicle maintenance plan, discussed in Section 5, "Railcar Maintenance's Role in Lifecycle Management Planning."

Trainings typically focus on one of the two skill types: technical maintenance skills or general skills—problem solving, communication, teamwork, etc. Different types of training better address these two different types of skills. There are three main types of in-house trainings that give mechanics the skills they need for maintenance and repair:

1. Classroom
2. On-the-job
3. Apprenticeships

Each of these types of training is discussed in the following sections.

Classroom Training

Effective classroom training places an emphasis on participants' conceptual understanding—for instance by demonstrating the mechanics of how different components work together—and incorporates application whenever possible. The creation of an interactive environment where employees spend less of their time sitting and listening and more time actively participating with the material and with the instructor generally increases engagement and helps employees retain more of what they learn. A classroom setting can be well-suited to teaching general skills. For instance, it allows participants to break into small groups for team-building and communication exercises. Classroom-based training can also serve for management updates and discussions of agency-wide and department-wide goals (5).

Considerations when conducting classroom training include:

- Having an instructor who is familiar with an agency's maintenance work will ensure that the instructor has the most current knowledge and is administering a curriculum that is relevant to the specific demands of the workplace.
- Incorporating discussions and rotating groups of students through learning stations can help make the experience more interactive and help break up the monotony of pure instruction delivery
- An effective training should be a reasonable length to avoid student disengagement and have a small student to instructor ratio in order to maximize interaction (5)
- As employees acquire new skills, it is important to ensure they have opportunities to deploy these skills directly

While formal classroom training is often the default mode of training, it lacks the hands-on application component on-the-job training offers that is necessary to stimulate employees and facilitate the learning process; often times students learn better through doing rather than listening (5). If students are not able to practice what they are learning, it may be more difficult for them to retain the information and for the instructor to foster engagement (9).

Vehicle System Models for Training and Bench Testing

Bench (as well as portable) testing equipment is widely used in railcar maintenance, especially by electronics technicians. Such tools can also be a valuable training tool, especially if they are configured to provide users with an understanding of the system's overall functions, architecture, and logic. For bus maintenance, the "bus-in-a-box" is a common tool for testing onboard radio and automatic passenger counter equipment. The bus-in-a-box is usually a converted tool bench which clearly shows the onboard system's architecture, including all connections between components. The bus-in-a-box allows rapid testing of components to detect faults and checked repaired items, but it also helps mechanics and technicians unfamiliar with complex electronic systems to quickly learn about the system and supports their performance of basic maintenance tasks. Where shops can develop such bench test models of systems, they are a valuable tool for both training and maintenance (31).

On-the-Job Training

On-the-job training consists of training employees on the shop floor by observing and working alongside other mechanics, learning through demonstration and practice of procedural application. Instructors are typically high-level mechanics or supervisors.

On-the-job training can happen formally or informally. Managers and foremen can promote informal on-the-job training by encouraging workers to form mentorship relationships. High skill workers are valuable resources whose expertise should be leveraged for training. Peer-based training offers opportunities not only for knowledge transfer, but also to develop collaboration and leadership skills and to broaden key employees' career development options. For example, in some agencies junior employees rotate through positions matched to senior tradesmen to acquire skills. At Southeastern Pennsylvania Transportation Authority (SEPTA), experienced mechanics can apply competitively for mentor positions and must meet objective requirements to be accepted. Mentors in the program oversee formal classroom and on-the-job training for junior mechanics (10).

On-the-job training can provide a more engaging learning experience than classroom training because workers are actively practicing what they learn and the learning responsibility is shifted away from the instructor and onto the student. Students are not only introduced to tools and equipment, but also to the idiosyncrasies that may exist for each vehicle type (11), (12). On-the-job training is best used for inexperienced employees who could benefit from being in the work environment. However, on-the-job training alone may not be sufficient for positions that require a high skill level. (11) High skill level positions may require classroom training to introduce complex ideas and enhance understanding of underlying concepts and background knowledge. On-the-job training also may tend to follow current work demand, which may prevent students from undergoing a comprehensive technical curriculum.

Computer-Based Training

Managers in railcar maintenance recognized the advantages of computer-based training (alternately known as "e-learning") early. New York City Transit first adopted a computer-based training program for railcar maintenance supervisors in the early 1980s because it could deliver self-paced, individualized instruction on the supervisors' schedule. The system also enabled tracking of employees' progress and performance over time. The course materials covered both general skills such as background knowledge to enable interpretation of technical documentation and technical information such as standard operating procedures and standard inspection procedures and remain a model of an effective computer-based training program (16). More recently, New Jersey Transit has adopted e-learning in maintenance to compensate for greater training needs due to an increased retirement rate. Managers cite the usefulness of focused training to address specific challenges that can be completed opportunistically. By administering self-study courses that are broken down into small, usually computer-based modules, training is delivered in manageable units which employees can more easily fit into their workday. Participants emphasize their enthusiasm for engaging training materials and including interactive elements such as simulations and quizzes that teach. The agency cites the program in part for improvements in reliability (30).

Apprenticeship Programs

Apprenticeship programs are occupational training programs used to establish an employee's expertise in a field with a broad set of skills through a long-term career development process. Apprenticeship programs typically focus around meeting an industry or other widely accepted certification standard such as the American Public Transportation Association's (APTA's) Rail Vehicles Maintenance Training Standards, excerpted in Figure 6-2. They provide a combination of classroom instruction and on-the-job learning, supported by various kinds of testing and evaluation, and typically last from two to four years. Apprenticeship programs usually rely on traditional sequential training, which stresses the cumulative build-up of knowledge, with each level of instruction providing a foundation for the subsequent more technical level. Newly hired mechanics do not always possess the required technical skills, so a common hiring practice in agencies with well-established initial training programs is to hire mechanics based on their aptitude rather than on skill alone and rely on an apprenticeship program to train up the new employees (5). The APTA training standard excerpted in Figure 6-2 emphasizes technical skills, both general and by vehicle system, that railcar mechanics and technicians should master. However, the standard does not address general skills that can be critical in establishing a high performance maintenance organization.[33]

Figure 6-2

Excerpt from APTA's Rail Vehicles Maintenance Training Standards

205. Friction Brakes: Introduction and Preventive Maintenance
205.1 Hydraulic Braking
Inspecting and maintaining hydraulic braking
- Analyze fluid
- Bleed system
- Check fluids
- Check system pressure
- Depressurize System
- Explain cause of low and high fluid readings
- Explain causes of fluid breakdown
- Explain fluid flash point and related safety precautions
- Fill fluids
- Flush fluids
- Identify braking system check point/sight glass location
- Identify contaminants and their effect on fluid appearance
- Identify different fluids and their uses
- Measure vehicle weight to set brake effort
- Recycle fluids
- Set up flush cart with proper piping
Inspecting and maintaining flush cart
- Change filters
- Reset pump pressure
- Clean flush cart
- Explain meaning of different fault codes
- Describe load cells

Source: APTA, Vehicles Training Joint Steering Committee (13)

[33]The standards are available at www.aptastandards.com/Portals/0/Rail/MaintTrain/vehicles.pdf.

Apprenticeship Program at LA Metro

LA Metro has a certified mechanic training program that consists of technical classroom instruction and on-the-job training in operating division maintenance shops. The 18-month program, which is the result of a union agreement between LA Metro and ATU Local 1277, is taught by an Equipment Maintenance Instructor and the curriculum covers the diagnosis and repair of bus mechanical problems. Candidates are chosen by union seniority from the service attendants that apply for the program; the 2012 class had an applicant pool of 132 service attendants, and only 13 were selected to participate.

The training program puts the selected service attendants on a career track with an established track for career advancement. It also motivates other service attendants since their work performance is a criterion for selection for the program. As the technologies of newer fleets evolve, so do the skill demands for maintenance employees. LA Metro has encouraged its new class of mechanics to keep up with this skill demand by evolving their profession and continuously striving to learn and invest in their skill development (29).

Given the length of apprenticeship programs, they can serve as a valuable early career development path for employees, and managers can easily verify an employee's success by tracking the employee's progress in the program. Apprenticeships are usually only open to new employees or to employees within the agency in assistant or lower grade mechanic or technician positions (5), (12). An effective apprenticeship program goes beyond the usual structure to combine with other trainings that can give employees the interpersonal, collaboration, and problem solving skills necessary to support a high performing organization.

Keystone Transit Career Ladder Partnership

The Keystone Transit Career Ladder Partnership began as a local effort between SEPTA and the Transport Workers Union (TWU) Local 234, but has since expanded into a statewide transit partnership program. Labor and management work together to accomplish the shared goal of improving workforce skills through collaboration in the collection and analysis of skills and performance data. The partnership in Philadelphia is headed by a policy steering committee, made up of four representatives from SEPTA's management and four from the union. The committee is responsible for setting the policies of the training program and overseeing its function, including the work of several subcommittees that act as working groups for specific initiatives.

When the program began in 2002, a third party vendor was hired to work with the partnership to conduct the job task analysis, skills assessment, gap analysis, and develop the training curriculum. Having input from both SEPTA and TWU was an effective way of assessing training needs from two perspectives: front-line employees and operations management. This approach supported a dialogue that resulted in a shared understanding of training needs. The training program eventually supported the development of critical workforce capabilities with the goal of completing more vehicle maintenance work in-house. Training programs earned more credibility and interest since they were supported by both the union and management, and involved employee input. A key factor to the success of the partnership was having a neutral third party, the vendor, objectively assess the facts and guide the workgroups through their differences to stay on task. Using the data the vendor produced from the skills assessment, both sides were then able to agree on a training approach. Through the first year, the Keystone program trained 134 workers, exceeding the initial target of 107 workers. By the end June 2003, the program had trained 785 workers, more than double their initial target of 300 workers (34).

Providing Targeted Training for Railcar Maintenance Leadership

As railcar maintenance programs adopt new maintenance approaches and increasingly emphasize proactive maintenance and approaches like Total Productive Maintenance, junior and mid-level managers' roles rely more on advanced managerial skills. Generally, managerial responsibilities fall into four categories:

- **Planning.** Managers are responsible for planning the use of the maintenance organization's resources to reach their team, department, and overall agency goals. To reach high performance levels in maintenance requires more sophisticated and effective planning, relying on historical data and close communication with subordinates and other teams and department to develop accurate workload forecasts and on the use of advanced planning tools, such as scheduling functions of the CMMS. Effective planning requires strong quantitative and organizational skills.

- **Organizing.** Managers are responsible for the organizing of human resources to effectively accomplish their team's workload. They must divide human resources into functional teams that reflect lines of responsibility, grouping of related functions, business processes, workload, and the skill sets of employees. Managers must have extensive institutional knowledge and the ability to identify improvement needs and opportunities related to both human resources and business processes.
- **Directing**. Managers must ensure that employees' work effectively supports organizational goals. Managers are responsible for coordinating their subordinates' work with other teams and departments. Flexibility and communications, facilitation, and problem solving skills are critical for the directing function.
- **Controlling.** Managers are responsible for ensuring planned tasks are executed effectively and that work completed effectively supports the organization's goals. Management control requires expertise in the use of the CMMS and ERP, understanding of data collection and performance management, and knowledge of other, more focused management control approaches (14).

APTA's Proposed Core Competencies for New Transit Supervisors[34] reflect these four functions and identify specific skills to seek when selecting new managers for railcar maintenance or to use for career development goals for existing managers. APTA's competencies focus on communications skills, oversight of subordinates' training and career development, interpersonal skills, work planning and management, safety awareness, problem solving and conflict management skills, adaptability, and decision-making (15). Soft skills, such as communication and facilitation, help maintenance managers act as enablers for employee initiative and problem solving (5).

The Metropolitan Transportation Authority's "DELI" Luncheon Series

New York's Metropolitan Transportation Authority (MTA) initiated the DELI ("Dialogue, Engage, Lead, and Innovate") luncheon series in which mid-level managers and executive staff meet to exchange ideas and discuss issues and initiatives. The DELI series encourages communication between managers and gives them information that they can share with their staff. It provides a value forum for managers to learn from each other's experiences (23).

See APTA's website, http://www.apta.com/resources/profdev/webinars/supervisory/Pages/default.aspx.

Management Development at Greater Cleveland Regional Transit Authority

The Greater Cleveland Regional Transit Authority (GCRTA) has a management development program that is used train employees to develop their cross business and cross functional expertise. The program runs for 20 to 22 months, and each participant goes through four to five rotations that last six months each. The selection process is targeted primarily towards recent college graduates that demonstrate academic excellence and strong analytical and critical thinking skills. Upon successful completion of the program, participants are placed into positions that have high organizational impact and encourage growth and succession. The program has been successful because it has provided a pipeline by which the agency can develop future leaders; not only does the program demonstrate a commitment to career advancement, but it also encourages continuous training, development, and mentoring. The program also has high visibility with senior leadership and enables participants to build relationships across all levels of the organization. The agency was also able to gain buy-in because of the recognition that the newer generation of employees had their own ideas and skill sets to offer. Cultivating these skills and ideas were seen as an important part of succession planning and investing in the future of the organization.

Participants of the management development program started a Future Leaders Club that provides the workforce with professional development opportunities, career guidance, and networking opportunities. Professional development seminars are held on a monthly basis; speakers include leaders from within the organization as well as business leaders from Northeast Ohio and Canada. Speakers cover a broad range of topics, from leadership to professionalism, and share their practical knowledge and experiences within their field (35).

Technical knowledge is also critical for managing railcar maintenance. Supervisors need to be able to identify the resources necessary to complete a task and be able to interpret manuals, diagrams, and other technical documentation and communicate it to others. They must also be able to evaluate work and diagnose problems (e.g., car equipment troubleshooting), and use these experiences to make decisions on how best to manage technical resources (16).

Quantitative and planning skills are important to effectively manage the growing complexity and technological sophistication of railcars and the higher number of specialist and expert technical staff. These factors demand that managers have more than the traditional mechanic and management skills to be able to effectively lead and motivate the workforce. Maintenance managers must also be able to support the shift towards becoming a high-performing work organization with the ability to implement more sophisticated maintenance approaches such as with Reliability-Centered Maintenance and Total Productive Maintenance practices. Tracking performance requires supervisors to be highly engaged with their staff on a regular basis in order for them to understand how personnel skill sets can support overall organization goals and have the managerial skills to be able to plan for the processes best suited to address department needs (17).

Finding Time and Funding for Training

Many agencies know that their workers need additional training to upgrade their skills, but it can be challenging to allocate time and resources for training. Managers are often reluctant to pull workers from their daily responsibilities to administer training and may choose to use overtime instead. Allocating additional funding for training from budgets that are already constrained can be challenging when training is not seen as an investment in human capital, but rather an expense and a fulfillment of regulatory compliance (5).

It is important to consider the potential benefits of any training offered to employees. Trainings are most valuable when they provide a quick return on investment. By carefully adhering to several basic principles, managers can ensure the effectiveness and value of trainings:

- Trainings should reflect timely business needs.
- An effective training is pertinent and actionable for participants: an employee should be able to put the material to immediate use.
- The training material should be at the appropriate level. The training should cover mostly new material, but it must ensure the employee has appropriate background or foundation knowledge to understand.
- The training should be engaging to maximize participants' engagement and the knowledge they take away (8).

While these are basic, non-controversial ideas, their implementation can require significant work on the part of staff responsible for preparing trainings. In general, short trainings are easier to schedule into the workday and take less time to prepare, but even minor trainings should adhere to the criteria listed above. When deploying trainings to address an existing performance issue, it is important to base that decision on actual performance data to ensure training resources are being used to address the most critical needs. Managers should select employees for participation based on who is most likely to benefit from the training. Criteria for the inclusion of an employee might be their area of specialty, a qualitative judgment of their level of skill, or performance data from the CMMS, such as comebacks (18), (5).

Using Downtime for Training

Time for training should be prioritized by taking advantage of employees' natural downtime (5). Downtime can sometimes occur as a result of an uneven maintenance workload. Downtime may also vary across shifts—there may be more downtime during peak hours when vehicles are in service, whereas the time period in which vehicles are not in service and maintenance is being performed will result in less downtime. There may also be downtime during unexpected occurrences, such as delayed parts preventing the completion of maintenance work. If managers can prepare a training program to take advantage of these various opportunities, it is possible to ensure the productive use of downtime and minimize the time investment needed for training.

Flexible and concise trainings work well with a down-time approach, in contrast to the more structured and lengthy nature of traditional training approaches. When managers foresee downtime in advance, they can plan more extensive trainings. When employees have sporadic availability, training strategies such as web-based training or informal trainings with short durations, sometimes lasting no more than 10 minutes or a quarter of an hour, can be used. This can be as simple as a supervisor discussing how to troubleshoot a specific maintenance problem that the shop has recently faced. Such trainings may occur at the discretion of the foreman or supervisor and topics should cover current or ongoing issues. Often such training is peer-based, with a mechanic or technician preparing the material and taking the lead role in training a small group. The participation of frontline employees encourages individuals to develop specialties, such as the use of specialized equipment, quality assurance, the use of the CMMS, or workplace safety, and can constitute part of employees' career development. The best use of downtime for training is to supplement existing knowledge rather than administering informal trainings in lieu of a comprehensive curriculum to establish the base mechanical knowledge. A combination of flexibility and accountability both in the training program and in employees' roles allows individuals to take more control over their learning experience and make the most of it.

Stretching Training Dollars

Allocating sufficient funding for training can be challenging but there are many innovative approaches, such as forming a training consortium with other agencies, creating a partnership with a local community college, or opening up training courses to a wider audience to reduce an agency's in-house costs. Sharing training course material with other agencies can help agencies make the most of limited resources (89). This is also beneficial to the transit industry as a whole; if training guidelines are standardized and the best trainings from different agencies are pulled together, the result is a valuable resource pool that represents agencies' areas of strength.

When transit agencies support employees' participation in external education and trainings, it can be useful for managers and employees to map out training goals both to encourage employees' use of the benefit and to maximize value for both parties. Such planning typically occurs on an annual basis. Another benefit of such planning is that it affords a valuable opportunity for a manager to provide feedback to the employee and emphasize areas where the employee needs development. It is also an opportunity for employees to communicate their career interests and long term goals. Regular meetings focused on career development can help improve employees' performance by providing feedback on their past performance, communicating expectations for future performance, and supporting employees' improvement efforts. Such meetings also give employees an opportunity to present their own expectations for their career and help employees understand how to achieve their career goals. The meeting outcomes should be summarized by either the employee or the manager, confirmed by the other, and placed on file for future reference (5).

In order to verify training's cost-effectiveness, managers may pilot trainings with a subset of target personnel. The initial investment in the training is reduced, and managers can evaluate the success of the training by comparing participants' performance before and after the training. They can also compare participants post-training performance with non-participants. Based on the change in performance, managers should be able to at least ascribe a rough value estimate to the training. Keeping track of costs in conjunction with the benefits can help justify the investment in training in the long run (5). Investment in training planning and development is critical. Agencies need to determine which training strategies work best for them, target resources towards those needs that are most pressing, and emphasize high quality in every training.

After conducting training, it is important to evaluate the effectiveness of the training. It is the manager's responsibility to ensure that each training has an effective evaluation strategy in place to ensure the training meets its goals and to implement improvements for future trainings (see call-out box). For long standing trainings, such evaluations should be conducted regularly. When a training program has explicit, measurable goals, it both helps participants to focus and allows managers to subsequently effectively measure the effectiveness and value of the training. Measuring the success of a training program can include feedback from employees. A short evaluation form focusing on participants' engagement is effective for measuring the value of the training from the participants' perspective. However, employee evaluations are not a substitute for objective measurement of the training's success (18).

Southern California Region Transit Training Consortium (SCRTTC)

The Southern California Region Transit Training Consortium (SCRTTC) is a partnership between community colleges and transit agencies that work together to develop resources that can be used to develop the transit industry's technical workforce. The SCRTTC is funded through a mixture of sources, primarily grant funding and membership fees, however the organization also benefits from the shared resources of its members.

The partnership builds training capacity for transit agencies and results in a unique pool of shared knowledge from both experts from the community colleges and transit agencies. The community college members and transit members both have training topic inventories that are reviewed and updated on a regular basis. The inventories are not only representative of courses that address current skill needs, but also the larger transit industry training needs. These inventories are a result of needs assessments conducted through interviews, surveys, meetings, and site visits. The SCRTTC trainings are available to agencies that may not have the resources to fund trainings themselves (36), (33).

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Measuring the Effectiveness of Trainings

Managers should ensure they can effectively measure results. One approach is to conduct a before and after comparison using data from the CMMS to understand the change in comebacks, time to repair, or other key performance metrics. Another assessment approach is to conduct an evaluation of skills learned in the training. A written test may reflect some of the knowledge acquired by the employee, but practical tests are preferable to provide an accurate representation. Probably the best way to measure the effectiveness of trainings (as well as other performance improvement measures) is to compare the outcome of those undergoing the training to a control group who does not undergo the training. The more focused the training or its components, the easier it is to measure effectiveness. For instance, the effectiveness of a training related to brake system repairs should be reflected in the subsequent maintenance data. Managers can implement comparisons by select a particular team, shift, or facility to undergo the training while maintaining a comparable control group. When managers can measure the benefits of a given training, it becomes much easier to justify the level of resources expended for the training.

External trainings can present more of a challenge for measuring the effectiveness of performance. External trainings often have a broader scope than internal trainings—for instance pursuit of an accreditation vs. understanding a particular diagnostic procedure—which makes assessing their value more difficult. However, when selecting external trainings or approving an employee's choice of external trainings, the manager still needs to consider the intended outcome of the training in light of the questions that would apply to an internal training: what need is the training addressing, how is the training appropriate for the employee, and how is it possible to measure the outcomes of the training? In the absence of objective measures, qualitative answers to the questions can still provide valuable information. Moreover, it is necessary to follow up to understand whether the training met expectations and to note potential lessons or improvements for the future. The various levels of performance measurement include the following:

- Training participation: track how many employees are participating in the training over a given period of time
- Participant attitudes: measure the participants' opinions on training and its effectiveness
- Learning: assess what the participants actually learned through the training, which usually involves before and after testing
- Application: evaluate the extent to which participants actually apply the skills or knowledge acquired through the training, which can involve ongoing observation
- Business impact: evaluate the extent to which training has addressed the business issue it was intended to target
- Cost-effectiveness: model the cost-effectiveness of training to understand its ultimate value to the organization
- Optimization: update training program based on observations of effectiveness (18), (32)

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Preparing for the Requirements of New Technologies

The introduction of new generations of vehicle technologies, maintenance equipment, and information technology to a railcar maintenance program usually requires mechanics and technicians to upgrade their skills in preparation by becoming familiar with new equipment and learning new skills and maintenance procedures. As railcars increase in complexity, maintenance workers are expected to maintain vehicle systems that are both more advanced and more diverse (18). If the transit agency does not address such training needs, the railcar maintenance program is likely to see impacts on employee productivity, vehicle down time, and vehicle reliability, with declining overall vehicle availability (5).

Training needs to be carefully planned well ahead of the delivery of new vehicles so that mechanics and technicians have adequate time to prepare for the new assets. Giving technical ownership of a new system to a core team of maintenance staff and providing the members with intensive training establishes training leads for the remaining workforce (a "train the trainer" approach). Training is a critical investment in the success of new vehicles or systems, but agencies do not always budget sufficient training resources as part of the upfront capital cost of a major procurement (5).

SEPTA's Skill Gap Analysis in Preparation for New Vehicle Delivery

As part of the procurement of the Silverliner V railcar, SEPTA conducted a skill gap analysis covering both the existing fleet and the new fleet. The goal of the assessment was to understand the workforce's shortcomings so that they could be addressed in the eighteen to twenty-four month window preceding delivery of the new vehicles.

The assessment included first an analysis to understand the specific skills needed to support SEPTA's railcar maintenance business processes and job tasks. More than 500 job tasks were broken out by criticality and mapped to more than 30 positions. The skill requirements developed included performance standards or benchmarks to provide a baseline target for the organization to meet. Next the assessment evaluated the workforce to understand the current level of skills. Finally, the evaluation compared the existing skill levels against the skill requirements developed to understand the current skill gap. Through the assessment process, SEPTA was able to identify specific areas to focus training efforts, such as giving electricians a better conceptual understanding of how programmable logic controller function and improving mechanics' basic computer skills. The resulting training program included a mix of general trainings in foundational skills and targeted training for higher level skills such as specialty diagnostics (6).

Transit agencies can use test vehicles in the acceptance and safety certification period to have the original equipment manufacturer (OEM) demonstrate maintenance procedures and to give maintenance staff early familiarity with the vehicles ahead of delivery. Also, an initial OEM support period allows hands-on training, which the agency can document with video cameras and photographs to develop its own tailored training materials. Support periods also give at least a subset of frontline workers the opportunity for on-the-job training with specialists from the OEM.

The OEM's technical documentation can be useful throughout the life of the vehicle. The OEM typically is required to provide detailed technical documentation to accompany maintenance manuals, including high quality system diagrams and figures. Over the course of the vehicle's useful life, maintenance staff can update and adapt technical documentation to better document maintenance procedures for training and resource purposes.

Preventing Maintenance Knowledge Loss

Even within large maintenance organizations, many individuals may possess critical expertise and institutional knowledge not available elsewhere in the maintenance program. More generally, the skills and knowledge that come with a long career as a mechanic, technician, or engineer working on a particular system are not easily or quickly transferred and require careful succession planning and investment to avoid their loss. It is important that the maintenance program have a knowledge transfer strategy in place to ensure critical knowledge and skills are not lost through retirement or other kinds of turnover (20).

One of the key strategies for knowledge preservation is practical documentation of maintenance knowledge. Documentation requires an ongoing effort to record practices, requirements, specifications, plans, and other critical documents in useful, indexed formats. Maintaining documentation requires an ongoing commitment, but the more practical the information is, the more benefits the maintenance program will reap, especially in supporting training of employees new to positions. For instance, as part of its Strategic Maintenance Program, one heavy rail operator's vehicle maintenance managers made improvement of maintenance procedure documentation a priority. Senior mechanics, foremen, quality assurance staff, and supervisors were given greater control of and responsibility for keeping documentation up-to-date and improving its practicality. The fleet managers emphasized the use of diagrams, photos, and practical tips. The agency also emphasized adding explanations of the purpose and concept behind tasks and steps so that maintenance staff could better understand tasks conceptually.

Another strategy to provide redundancy for critical workers and improve career path opportunities for experienced mechanics and technicians is to create a program for part-time shift coverage for critical positions. Under such cross-training, the employees undergoing cross-training takes time off of their normal role, typically covering less critical shifts, and receives mentoring from the position's incumbent. Training up of such workers is a good opportunity to assemble and update documentation into practical, indexed formats. Moreover, the extra coverage frees up the incumbent employee's time for such training and documentation activities. "Understudy" workers also benefit from the opportunity to develop new skills, specialize, and take on additional responsibility (21), (5).

Succession planning is a systematic approach to help organizations prevent the loss of critical knowledge and capabilities when employees resign or retire. Succession planning identifies key areas of risk for knowledge and skills loss as well as prevention strategies. It is good practice to review employees on an annual basis, particularly all specialists and managers, to understand which employees are likely to retire, which possess critical knowledge and capabilities unique within the organization, and which possess knowledge and skills that would be difficult or impossible to get through a new hire (22). Railcar maintenance managers can conduct a simple risk analysis where each employee is scored on these factors to create a weighted average score. Managers can then develop risk mitigation strategies to the most critical employees (20). For example, one strategy is to identify internal candidates to fill these positions and create a career development plan to prepare them by the expected succession date. Development plans should map out specific training needs and milestones that are necessary to gain a level of proficiency to take over for key employees (3). Annual succession planning should chart year-on-year progress and identify where development plan and other existing strategies are falling short of goals.

Other strategies to address succession risks include:

- Identify key competencies and knowledge candidates must possess to fill critical positions.
- Maintain and regularly update career development plans for all staff, focusing on coverage of critical positions.
- Develop and improve the documentation of practical knowledge needed for the position.
- Minimize incentives for critical retirement-eligible employees to leave organization (23).

Supporting a Positive Maintenance Culture

The vision for a productive maintenance culture centers on careful attention to work quality and the needs of the end customer, the active identification of opportunities for improvement, and rapid response to emerging issues. Railcar maintenance managers can support improvement of their department's maintenance culture in part through a focus on employee engagement, recognition, and performance incentives. The vision is to have employees take ownership not only of their own work but that of the maintenance department and transit agency as whole, building a sense of shared responsibility for the agency's service quality. When workers are not invested in the organization's vision, they have less motivation to carry it out. A work culture that appreciates and recognizes its employees' contributions, respects their autonomy and input, and provides visible opportunity for career development and advancement can contribute to improved employee morale and increased productivity and performance. Note that supporting a positive work culture is also a critical success factor for Total Productive Maintenance (TPM) (see Section 3), which relies on the engagement and leadership of frontline employees to realize continuous improvement.

Recognition and Incentive Programs

Within the transit industry, recognition and performance incentives are widespread strategies to motivate the maintenance workforce and reinforce the maintenance culture. Recognition looks retroactively at employees' performance while performance incentives create a broad-based, transparent framework for rewarding future success. The goal of recognition programs is to reinforce positive behaviors, clearly express appreciation for good work, and align employee incentives with those of managers (24). Recognition programs can help build role models for maintenance employees at all levels and stages of their careers and thereby reinforce the organization's values. As part of a recognition program, a maintenance program may also confer certificates or titles that reflect a maintenance employee's skill and role progression and provide a sense of career advancement without formal promotion. Both recognition and incentive programs must closely reflect the organization's overall values and be based a transparent award process (25).

Like recognition programs, incentive programs are intended to communicate clear priorities and performance targets to employees and to focus the maintenance organization. They tend to be more broad-based, rewarding all employees who meet a certain performance threshold. Some agencies use employee incentive plans to reward maintenance productivity, quality, and innovation and to reward employees for meeting goals related to operating performance, safety, and attendance (26). Incentives can range from monetary rewards to extra vacation days.[35] Another major incentive for employees is career advancement; establishing a transparent career path will give employees goals to aspire towards. Employees are often rewarded collectively at the team, functional, or division level. Common employee incentive programs for transit vehicle maintenance programs include the following:

- **Merit pay**. Salary increases and promotion are based on employee performance reviews and performance targets set in advance.

[35]Though collective.

- **Individual performance bonus**. A bonus program is similar to merit pay but consists only of a one-time reward for work performance.
- **Non-cash incentives**. Similar to a bonus program, except employees only receive non-cash prizes and special perquisites for work performance.
- **Suggestion plan**. Individual employees, functional teams, or quality improvement teams are rewarded for suggesting successful cost-saving or performance improvement ideas.
- **Labor cost savings program**. Employees participate in a process to drive labor productivity and work quality and share collectively in the overall savings or benefit generated through a bonus or other sharing program.

Typical performance measures for incentive programs include productivity measures such as total preventive maintenance inspections completed in the last period, quality measures such as number of comebacks for an individual employee or functional team, or financial measures such as staying within a program's budget or minimizing use of overtime (27).

Promoting Employee Engagement

When employees are engaged with their work and the agency goals and objectives, they have an incentive to invest in their own skill development and support continuous improvement efforts. Employee empowerment is defined by the sense of control employees feel over their work and decisions. Empowerment of employees comes from giving them greater autonomy in their work and decision-making, but also from raising their level of accountability to ensure they feel responsible for outcomes. Clearly established standards, goals, and objectives help to motivate workers. As goals set by management flow downward through the organization, feedback from the frontline workforce flows upward (5), (2).

Giving frontline workers regular opportunities for input ensures that their concerns receive attention from management and that distracting issues do not provide an excuse for lack of progress. During major changes and transitions, meaningful input to and involvement in decision-making processes helps ensure greater support for the final direction and less resistance to change. When employees are involved in the development of solutions, they not only provide high quality practical information, but they are also more vested in ensuring the selection and implementation of successful solutions. Employee participation may include direct participation, consultative participation, informal participation, representative participation, or full ownership of the process. Each of these can, to varying degrees, increase employees' cooperation and effectiveness in supporting TPM and other initiatives, as well as their satisfaction with the process. For example, self-directed work teams consistently show lower absenteeism and turnover rates. They also free up management resources for higher value-added tasks such as quality assessment, maintenance planning, and continuous improvement. Other performance improvement approaches like quality circles and autonomous maintenance (see Section 3) also promote a positive maintenance culture by reinforcing the responsibility and autonomy of frontline workers to provide input, make decisions, and ensure outcomes. To support these approaches, frontline workers need to build on critical skills including problem solving skills, business skills such as QA/QC and cost accounting and modeling, team building skills, and group decision making (28).

The vision for TPM is to maintain a department culture where all employees are proactively pursuing improved quality and efficiency. By giving employees more autonomy and a greater role in performance improvement, responding to their input, and investing in their work environment, TPM helps nurture a greater sense of ownership and engagement among maintenance workers.

Key Success Factors

- Managers regularly assess the existing workforce's skill sets to determine where skill gaps exist and which trainings best address agency needs.
- Managers proactively identify training needs as part of the department's planning processes.
- The department's training programs ensure workers have the knowledge, skills, behaviors, and attitudes to carry out their railcar maintenance responsibilities.
- The department's training programs support individualized career development for employees.
- The delivery method for each training (classroom, on-the-job, etc.) is appropriate to its goals and content.
- There is ongoing measurement of trainings' effectiveness.
- The department has clear career paths in place for its frontline and mid-level employees.
- Managers emphasize the use of opportunistic trainings to take advantage of employee down-time.
- The department offers ongoing training to develop the leadership and management skills of management staff at all levels.
- The department uses recognition and performance incentive programs to motivate employees to improve performance meet department goals.
- Succession planning, cross training, and related measures are place for critical positions to avoid skills/knowledge loss.

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SECTION 7

Supporting Processes and Systems

This section focuses on the supporting processes and systems on which a railcar maintenance department relies to effectively carry out its mission. Chief among these are the procurement, maintenance facility improvement projects, materials management, and information technology functions, which may be hosted in other departments but are integral to the railcar maintenance program's work. This section explores the role of each of these functions in railcar maintenance and presents management strategies and methods to ensure their effectiveness and support their improvement.

Every railcar maintenance program relies on several critical supporting business processes and systems to effectively carry out its mission. These include the following:

- **Rail vehicle design/procurement** – more than any other stage of the railcar lifecycle, the decisions made during the design/procurement stage determine the expected useful life, lifecycle costs, and performance of railcars.
- **Railcar maintenance facility projects** – new facilities or major upgrades to existing maintenance facilities offer an opportunity to improve vehicle maintainability, implement new maintenance capabilities to complete more work onsite, and raise overall facility capacity and efficiency.
- **Purchasing and materials management** – the overall goal of purchasing and materials management is to ensure the railcar maintenance mechanics and technicians have the right parts, of sufficient quality and in the right quantity, at the right place and time for an acceptable price.
- **Information technology (IT) support** – information systems can support all aspects of maintenance management processes; asset data needs to be stored, managed, and analyzed in one or more information systems for effective management.

These supporting business processes are often managed or "owned" by other departments. However, they are integral to the railcar maintenance department's work, and the department needs to closely oversee and cooperate with these critical maintenance functions. This section explores the role of each of these support functions in railcar maintenance and presents management concepts and strategies to ensure their effectiveness and support their improvement.

Vehicle Procurements

More than any other stage of the railcar lifecycle, the decisions made during procurement determine a vehicle's maintenance requirements and more generally its expected useful life, lifecycle costs, and operational performance. The initial design is the principal determinant of a vehicle's maintainability, and the quality of manufacture is a major determinant of a vehicle's reliability. To ensure effective management across the vehicle lifecycle, railcar maintenance managers are key stakeholders in railcar lifecycle management, and railcar maintenance staff needs to be included in all stages of a new vehicle procurement, major overhaul programs, and any fleet modernization programs.

This section explores procurement strategies that help ensure the reliability and maintainability of new vehicles through their entire lifecycle and addresses the role that railcar maintenance staff can play in the procurement process. These strategies include the following:

- Establishing effective program oversight to ensure vehicle quality
- Applying standards and common platforms to avoid problems with vehicle systems integration and other quality issues
- Using best-value procurements and evaluating alternative procurement options as ways to ensure successful railcar procurements from a lifecycle cost perspective

It is important to note that many of these same principles apply to the procurement of new rolling stock maintenance facilities and to the renovation or replacement of existing facilities, which contribute to fleet maintainability and can place constraints on railcar maintenance activities.

Program Oversight

For a new vehicle procurement, transit agencies typically establish a program management team responsible for overall planning of the procurement, development of requirements, oversight of the bid process, and oversight of the design and manufacturing stages. Through deep expertise, thorough quality assurance, and detailed planning, the program management team's goal is the delivery of a high quality vehicle with minimal lifecycle costs and maximum performance. Therefore, the program management team's scope of responsibilities naturally includes a significant role for participants from the railcar maintenance department. In many agencies, the vehicle maintenance department includes an engineering group that oversees vehicle procurements.

The program management team must have expertise covering engineering, procurement, program management, maintenance, lifecycle cost assessment, regulatory requirements, contracting, and risk management. Representatives from the railcar maintenance program typically play an important role in the development of technical specifications and in the review of bids and vehicle design, for example helping to address reliability and maintainability in the technical specifications and ensure that vehicle designs reflect the capabilities of the maintenance facilities. It is important to represent the full breadth of stakeholders in the railcar maintenance program, especially in larger agencies where responsibilities are more broadly distributed, so that the procurement process accurately reflects the department's business requirements (1), (2).

Maryland MTA LRV Procurement Program Management

When the Maryland Mass Transit Administration procured Baltimore's first light rail vehicles, it faced a tight timeline to ensure delivery and certification of the vehicles in time for the opening of the new light rail line in 1992. The establishment of an experienced program management team played a critical role in planning and overseeing the procurement and ensuring its final success. The program management team used a best-value procurement approach, focused on identifying and managing risks and minimizing lifecycle vehicle costs.

In Maryland MTA's first stage of procurement planning, the agency conducted a peer analysis of light rail vehicle technologies used across North America. The analysis took into account the vehicle design generation for the recent peer procurements and compiled a list of key issues to specially address in the procurement and to support comparison among technologies and against the technical requirements imposed by the new system right-of-way. Such issues included the brake system configuration, overpass clearance heights, propulsion control (AC vs. DC), system integration, and articulated versus non-articulated vehicles. As a result, in the course of evaluating proposals, the procurement team was prepared to conduct an analysis of each bidder's ability to successfully integrate critical systems, especially the braking and propulsion systems proposed.

In the development of the technical specifications, the procurement team focused on minimizing risk and maximizing performance in key areas, such as the propulsion system. The program management team conducted an analysis comparing lifecycle costs of AC and DC propulsion systems, ultimately opting for the former based on its superior record of reliability and better maintainability and the vendor's proven experience with the technology which were reflected in lower overall lifecycle costs despite higher upfront costs.

Throughout the manufacturing stage, the program management team kept a resident inspector onsite at the manufacturing facility and dispatched staff for regular visits to support key quality assurance tests and review results. Ongoing testing minimized the influence of final acceptance testing on the project's critical path and thus minimized the risk of delay in that critical stage. The program management team prioritized retrofits and corrective measures for issues identified in testing and provisionally accepted enough vehicles to provide revenue service in time to carry passenger to the opening day of Baltimore's new ballpark. Remaining lower priority retrofits were conducted for these vehicles on an ongoing basis.

The overall outcome of the procurement process was to balance an aggressive schedule with a program that emphasized risk management, quality, and management of lifecycle costs. As a result, the agency was able to procure high quality vehicles with a track record of good reliability and maintainability and also to meet the project schedule. The agency built upon this approach successfully with its follow on procurement three years later, working to further improve maintainability and performance of the additional vehicles (4), (27).

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The vehicle procurement program management staff is responsible for the creation of a detailed and thorough acquisition plan and oversight of its execution. The acquisition plan provides a roadmap for the procurement process, laying out each of the steps and deliverables. Railcar maintenance representatives are responsible for ensuring that the overall process meets the department's primary business objectives: maximizing vehicle reliability and maintainability. As a result, it is important to emphasize their participation at all stages of the procurement. Later elements in the acquisition plan may depend on earlier steps, such as the selection of a particular technology or platform or on the results of an analysis of different procurement approaches. For example, a decision to switch from DC to AC propulsion technology could have major downstream implications, affecting the railcar maintenance department's training needs and its collaboration with the right-of-way maintenance department overseeing power distribution (3).

The final responsibility of the program management team is to plan and implement a successful transition of the new fleet into operations. Maintenance workers must be receive training in advance to understand unfamiliar characteristics of the new fleet and learn new maintenance procedures, including the use of new bench test and other diagnostics equipment. Effective transition planning can reduce help costs and sustain reliability during the new vehicles' burn in period.

Vehicle Specification Standardization and Maintainability

Over-design can be an issue for U.S. light rail vehicle procurements. "Over-design" refers to specifications that are so prescriptive that they drive up costs and reduce competition from vendors. (1) Simplification of requirements and adherence to standards can help bring costs down, reduce risks, and give bidders more leeway to develop the best-value approach. To the extent that bidders can offer off-the-shelf designs which would reduce costs and offer similar performance, it is consistent with a best-value procurement approach and can mitigate risks related to factors such as systems integration and maintainability. When the program management team conducts early meetings with potential bidders, it can help the team develop a technical specification that maximizes access to off-the-shelf designs and allows latitude to manufacturers in key areas (4), (2), (5).

Unique vehicle designs minimize the opportunity for collaboration and coordination with other agencies to reduce costs (1). Buying existing railcar models helps reduce risk by selecting a proven vehicle with a broader market. Manufacturers and peers are more likely to provide support over the long term. Spare parts are likely to be less costly and less prone to have production discontinued unexpectedly (6), (5). When the program management team diverges from a technical standard or a proven platform, it is important to have a strong business case and conduct a full risk analysis, as Maryland MTA did when it selected an AC power propulsion system for a new light rail line. The use of standards and proven technologies is an important factor in vehicle maintainability, and the railcar maintenance department is usually well-positioned to help assess the risks of diverging from their use.

The U.S. Government Accountability Office has encouraged the further development and use of standards for passenger railcars in the U.S (6). High quality standards can help reduce agency's reliance on manufacturers using proprietary technology and support more robust supplier networks, bringing down both initial vehicle purchase costs and ongoing parts costs. The American Public Transportation Association's Procurement Terms and Conditions Working Group completed a standard request for proposals and technical specifications template for light rail vehicle procurements in 2011, the Light Rail Vehicle Request for Proposals (RFP) Procurement Guideline (see except in Figure 7-1). The template asks the respondent to define their approach to quality assurance and maintainability in the design and manufacturing processes. The specification guideline includes a comprehensive testing program and reliability demonstration process. It also includes maintainability standards for key vehicle systems (7). The standard form helps ensure that the procurement is based on a contract document that experienced manufacturers have worked with before.

Figure 7-1

Excerpt from APTA's Light Rail Vehicle RFP Procurement Guideline

TS 2.9 Maintainability
TS 2.9.1 General
1. The vehicle design shall incorporate standards that minimize mean time to repair (MTTR) and maintenance costs throughout its intended useful life.
2. The Contractor shall develop a maintainability program for the vehicle, including corrective and preventive maintenance, that shall provide for enhancement of vehicle availability and the minimization of maintenance costs.
3. The maintainability design for the Agency vehicle shall result in an overall MTTR of 1.8 h.
4. This shall be the weighted average of the MTTR of the key system elements as listed below. Diagnostic time shall be included in MTTR.
a. Traction equipment and controls shall have an MTTR of 1.8 h.
b. Friction braking equipment shall have an MTTR of 2.0 h.
c. Communications equipment shall have an MTTR of 1.0 h.
d. Side door and control equipment shall have an MTTR of 0.8 h.
e. Lighting equipment shall have an MTTR of 0.5 h.
f. Auxiliary electrical equipment shall have an MTTR of 1.5 h.
g. Coupler and draft gear equipment shall have an MTTR of 2.6 h.
h. Truck and suspension equipment shall have an MTTR of 1.6 h.
i. Train-to-wayside communications equipment shall have an MTTR of 1.0 h.
j. Carbody and appointments shall have an MTTR of 2.1 h.
TS 2.9.2 Maintenance Plan
1. The Contractor's maintainability program shall include a detailed plan outlining all schedules and activities for vehicle preventive maintenance.
2. This plan, along with the outline of the proposed maintenance manuals and associated drawings, shall be submitted to the Agency for approval within 120 days after NTP (CDRL).
3. The plan shall outline each maintenance task, the time schedules, recommended tools, personnel and skill levels required.
4. These recommendations shall be based upon those of the Contractor and of the equipment suppliers.
5. The weighted average of the component MTTR shall illustrate compliance with the overall MTTR requirements.
6. This plan shall be coordinated with the maintenance manuals and shall agree with them.

Source: APTA (7)[36]

[36]Available online at www.aptastandards.com/StandardsPrograms/ProcurementStandardsProgram/LightRailProcurementTechSpec/tabid/319/language/en-US/Default.aspx.

IEEE Railcar Standards

The Transportation Cooperative Research Program (TCRP) sponsored a research project to develop interface standards for electric rail passenger vehicles. TCRP worked through the Institute of Electrical Electronics Engineers (IEEE) and the American Society of Mechanical Engineers (ASME) to form the Rail Transit Vehicle Interface Standards Committee (RTVISC) and identify key standardization areas for system and subsystem interfaces for light rail, heavy rail, and commuter vehicles. Areas of standardization include: communications protocols on trains, communications-based train control, health-monitoring systems, safety standards for software systems, VOBC/propulsion controller/motor/brake, auxiliary power systems, vehicle passenger information standards, and environmental standards for rail transit equipment. Working groups consisting of more than 300 participants were formed for each area; each group is responsible for drafting proposed standards in their area. Participants include individuals from transit agencies, suppliers, consulting firms, and government and other interested organizations. At least 75 percent of the committee must affirm a standard in order for it to be published.

Standardization for vehicle and system design and operations is beneficial in establishing a base level of quality to help agencies increase reliability and cost-effectiveness. The procurement of vehicles has long been a high cost for agencies, and costs only continue to rise with the increasing incorporation of advanced technologies in vehicles. However, the supply industry is able to use the IEEE standards to ensure that they are building to common specifications, thereby increasing availability of parts to transit agencies and reducing prices. Standards counter the tendency of new technologies and customized designs to reduce system compatibility and limit suppliers. Standardization also helps to promote product quality by providing a precise basis for performance specifications and also serves to improve interfaces between systems built by different manufacturers by supplying a common architecture. The training process is also made easier through minimization of the differences in troubleshooting techniques and maintenance tasks across various suppliers. It is estimated that the IEEE standards have the potential to save the transit industry up to a third of a billion dollars annually (35), (30).

Best-Value Procurement

The purpose of a best-value procurement approach is to enable the owner to address lifecycle costs and mitigate vendor-related procurement risks, while meeting key performance standards for the assets being purchased. The program management team is responsible for defining key performance standards in the technical specification and for evaluating bidders with respect to cost, value, and risk. The best-value procurement approach accomplishes this first by designing for reliability and maintainability and focusing on manufacturing quality to help control lifecycle costs.

Miami-Dade Transit and Lifecycle Cost Analysis

Miami-Dade Transit (MDT) procured its first heavy rail vehicles in 1984 and planned to conduct a major overhaul beginning in 2004. Based on the bids received, MDT decided to conduct a lifecycle cost analysis to compare the cost of rehabilitation vs. purchase of new vehicles. The lifecycle cost analysis uses a net present value to compare the long-term costs, both capital and operations and maintenance. The lifecycle cost analysis showed MDT could save up to $140M over the 30 year forecasting period by opting to purchase new vehicles under a best-value procurement rather than rehabbing the existing fleet.

Such an analysis helps validate basic assumptions of the procurement and evaluate procurement options. Lifecycle cost analysis can provide a useful order of magnitude cost comparison of relevant procurement alternatives, which could include rehabilitation of the existing fleet, a low bid procurement, a best-value procurement, or an alternative procurement model such as a service contract where the manufacturer, in partnership with an investment company, supplies the vehicles for service under a lease and is responsible for their lifecycle management. Such an exercise helps an agency in its long term planning, reduces procurement risks, and helps ensure the delivery of a more reliable, higher quality fleet (34).

Lifecycle cost analysis, introduced in the call-out box above, is one of the most common methods to compare different bidders. A best-value procurement also relies on risk analysis to validate, to the extent possible, bidders' ability to successfully carry out the project. The railcar maintenance department staff's expertise can help validate the assumptions behind a best-value procurement and ensure the evaluation process reflects the agency's maintenance and performance priorities and requirements.

Costs and the so-called RAMS factors—reliability, availability, maintainability, and safety—are usually the key determinants of "value" with respect to maintenance. Maintainability, in particular, is a critical factor for determining "best value" and is largely a function of decisions made during the design phase. The complexity of a maintenance task is determined by design factors such as:

- The location and accessibility of the system
- Safety factors related to the maintenance procedure
- The diagnostics procedures
- The incorporation of testing capabilities to the system
- The resources required for maintenance including labor and expertise, facilities, and tools and equipment.

For each vehicle system, designers should use maintainability guidelines, developed in collaboration with maintenance staff, which acknowledge and address the resources and constraints existing or expected in the maintenance program. For example, a manufacturer should take into account the layout and capabilities of the existing facility (8). For the United Kingdom's Class 395 high speed train procurement, the manufacturer made maintainability a cornerstone of the design from the earliest project phases and developed maintainability standards for the design team based on visits to multiple high-speed train maintenance facilities serving other high speed rail systems. Since the vehicle procurement was for a new high speed rail line under construction, the train manufacturer was also able to play a role in the design of the vehicle maintenance facilities and provide valuable input to further improve maintainability (9). In some cases, it is possible to address design issues contributing to poor maintainability after vehicles enter service, for example, as part of a rehabilitation program. However, such re-engineering usually is only cost-effective for select cases, and it is best to identify and address such issues in the design phase (8).

Experienced maintenance technical staff members are well positioned to play an evaluation role in a best-value procurement. For instance, they can help identify specific areas of risk where they want to see more detailed information from the vendor. They can help with bid reviews, verifying bidders' assertion related to maintainability and lifecycle costs.

High quality diagnostics also contribute significantly to maintainability. As part of the technical specification and procurement process, the transit agency should assess the desired diagnostic capabilities to support maintenance and request these as part of the technical specification, prioritizing them if possible in the evaluation criteria to improve the quality of bids. Usually, much of the necessary test equipment for vehicle inspections and diagnostics is supplied by the vehicle or system manufacturer. As part of the specification, the transit agency should request that the vehicle manufacture specify necessary system tests for performance monitoring and diagnostics together with the required test equipment (10).

Improving Maintainability through Design Simplification

East Japan Railway Company runs one of the largest passenger railcar fleets in the world. The redesign of the company's standard electric commuter railcar was completed in 1998 and demonstrated the effectiveness of a design and procurement approach focused on minimizing the railcars' lifecycle management costs and improved their maintainability. The engineering approach emphasized simplification of the railcars—reducing components while maintaining or improving functionality—to improve reliability, maintainability, and initial manufacturing costs. For instance, the new Series E231 vehicles reduced wiring between cars by 80 percent and within cars by 35 percent. The design team also worked to include significantly more control capabilities in the new model's onboard computer to improve diagnostics and fault recovery for nearly every major vehicle system. In contrast to prior procurements, the railway maintained some of the manufacturing process in-house, using its production facility to test a variety of quality improvement strategies, such as increased manufacturing automation to reduce faults and labor costs, and to support more effective and lower-cost reconditioning of vehicles (29).

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LA Metro: Best-Value vs. Low-Bid Procurement

LA Metro's P2550 program, which consisted of the procurement of 50 light rail vehicles (LRV), encountered a number of design, quality, and workmanship issues that led to schedule delays in delivery. Metro had used a low bid process for vendor selection in vehicle procurement, which usually yields competitive prices, but does not fully take into consideration the risk of a selecting a bidder who cannot deliver specified vehicles under the contract terms, for reasons of cost, experience, technology, or other. A low bid process resulted in increased risk to the agency and higher overall lifecycle costs due to lower vehicle design and manufacturing quality resulting in higher operation and maintenance costs. The inherent risk of the low bid approach was compounded by an insufficient quality assurance program relying too much on the manufacturer's self-policing, which resulted in assembly work on vehicles resuming even when inspection findings were not fully addressed. Although the manufacturer was supposed to submit quarterly updates on estimated vehicle weight, only two or three reports were submitted, resulting in vehicles that were 5,000 pounds overweight upon delivery of the prototype vehicles. The identification of such major problems as overweight vehicles and system interface issues in the later stages of the procurement contributed to a significantly slower delivery schedule, and Metro eventually successfully sought damages through the court system. It is important for railcar maintenance managers to be aware of such risks and actively advocate in the procurement process to ensure they receive a quality vehicle which meets expectations.

LA Metro has taken the lessons learned from the P2550 program and applied them to their next procurement of P3010 series light rail vehicles. Rather than focusing on the lowest price, Metro took a best value approach in awarding the contract, assessing factors including technical compliance, schedule risk, and vendor program management in addition to cost. Consideration for these factors was crucial to reduce both project delivery risk and ensure a high quality product. In order to enforce quality requirements and ensure that technical specifications are being followed, the agency now uses a more extensive program management oversight process, including measures such as check points for inspection in the production process. Furthermore, the agency has employed performance-based contracting measures to better manage procurement risk. For example, the manufacturer is only allowed to proceed if it meets the agency's minimum quality requirements; milestone payments are tied to these requirements in order to keep the contractor accountable for quality control. The contractor must also present a master schedule, status reports, and mitigation plans for recovery of potential delays to keep the project on track for completion within the timeline initially set forth (33), (32).

Key Success Factors

- The agency uses best-value procurements for new railcar purchases.
- The agency has established effective program oversight guidelines for major fleet-related procurements, including new vehicle purchases and major rehabilitation programs.
- The agency uses lifecycle cost analysis to support decision-making related to the procurement model, critical design features, and bid selection.
- The department provides requirements and design review for new railcar procurements to maximize reliability and maintainability of new vehicles.
- The agency emphasizes the use of technical standards and other quality standards in major fleet procurements.

Railcar Maintenance Facility Projects

Railcar maintenance facilities typically have useful lives of over fifty years and must accommodate evolving fleets and maintenance needs. Agencies must plan new facilities wit consideration of facility requirements beyond the current fleet. Periodic facility improvements are needed to upgrade facility capabilities and capacity. Given the impact of maintenance facility capabilities and capacity on fleet maintenance operations, the railcar maintenance department must play a role in maintenance facility planning.

For major facility procurements, an agency can benefit from the engagement and oversight of the railcar maintenance department and from a program management approach similar to that covered in Section 0. Furthermore, a best-value procurement approach emphasizes the involvement of railcar maintenance staff to clearly define maintenance requirements and review plans and specifications. Major upgrades to maintenance facilities provide an opportunity to improve vehicle maintainability, expand on-site maintenance capabilities, and raise overall facility capacity and efficiency.

Maintainability is often a function of the constraints the maintenance facility imposes. For example, one hybrid locomotive manufacturer's battery design relied on a forklift, which, given the track layout in the maintenance bay, could not perform the task in the designated location. The removal and installation of batteries therefore required a more elaborate procedure, impacting overall facility productivity (11). Installing new equipment and adding new maintenance capabilities can allow staff to complete more maintenance on-site, which can reduce supply chain issues and vehicles down for parts and improve quality assurance and overall vehicle reliability. Facility upgrades can also improve work processes and improve overall facility productivity. Higher productivity raises the facility's effective capacity and can help postpone costly facility expansions.

For these maintenance goals to fully considered and implemented, it is critical for railcar maintenance staff to participate in each stage of the procurement process for a maintenance facility replacement or upgrade, including planning, design, and construction. As with any major capital investment, design changes later are more costly to correct and may not have any cost-effective remedy. As for a vehicle procurement, maintenance stakeholders can help define specific business requirements which address current operational needs and issues. They can also play an important role in design review to ensure the practical functionality of the design. Finally, maintenance managers must lead the transition planning, which encompasses moving into the new or upgraded facility while maintaining operations and which might include interim measures to accommodate onsite construction while continuing maintenance operations.

A Commuter Rail Operator's Maintenance Facility Transition

When a U.S. commuter rail operator began planning of its new central maintenance facility, the agency's fleet maintenance contractor was conducting light maintenance at outdoor sidetrack locations, and the agency had no heavy maintenance capabilities. The new facility was intended to expand the share of maintenance conducted in-house, improve working conditions and safety, and raise the quality of fleet maintenance and overall fleet reliability.

The operator's maintenance staff had extensive input into the facility design process. In the early project planning stages, the operator's engineering staff analyzed which maintenance tasks performed off-site were driving maintenance costs and vehicle availability. Based on this analysis, the requirements for the new facility included the capabilities to bring the most critical activities on-site. As part of the requirements building process, project staff also reached out to peer agencies for design ideas and lessons learned. Design reviews emphasized maintainability: efficient equipment positions and workflows to maximize the facility's efficiency and effective capacity. Other benefits of the new maintenance facility included significant environmental features, such as trackside power to eliminate diesel locomotives' idling and easier recycling of oil and other materials. Sanding and washing equipment onsite has helped improved the quality of service with cleaner train exteriors and more frequent painting of coaches.

From the project's groundbreaking through completion, an assistant manager representing the fleet department was onsite to support the agency's construction management staff and help oversee the contractor and provide input. Ongoing construction oversight meant that the contractor delivered the project meeting nearly all requirements, and a minimal number of modifications were needed after completion.

A Commuter Rail Operator's Maintenance Facility Transition (cont.)

The most challenging aspect of the project from the perspective of maintenance operations was the transition into the facility. In order to overcome the concerns of the maintenance contractor, reach consensus around critical issues, and ensure a successful changeover without any interruption to revenue service, the operator's fleet managers developed a comprehensive transition plan over the course of a year and a half. Through the stakeholder working group and technical assistance from consultants, the transition plan addressed issues such as the new facility's inclusion of equipment for heavier maintenance, including drop tables, a wheel truing machine, and an overhead crane. These would allow the operator to lower the average turnaround time for repairs and improve maintenance quality through reduced reliance on outside vendors. However, maintenance workers needed extensive training to use the equipment, and the operator had to plan to conduct the training before the new facility's opening while the new maintenance equipment remained under warranty. Finally, the new equipment and facility necessitated that the operator comprehensively revise its maintenance operating procedures. Using a three dimensional model of the site, the fleet maintenance contractor's employees were able to map out maintenance processes for the new facility from the arrival of a train through each chain of maintenance activities. Once the new procedures were finalized, the maintenance managers developed a training plan to ensure that staff would successfully transition to following new procedures, working with consolidate operations, and using new equipment. The transition plan relied on seven intermediate steps to manage the move in to the new facility. Through its successful planning process, the agency avoided any significant issues during the transition and was even able to accelerate the changeover.

The operator's fleet managers believe that the sense of ownership and pride of the workforce are critical factors to sustain a high quality railcar maintenance program. The managers saw the opening of the new central maintenance facility as an opportunity to shift the maintenance culture to a stronger customer and quality focus and used training to support this goal. At the new central maintenance facility, the workforce now benefits not only from high quality working conditions, but also from better employee facilities like locker rooms and receives clean uniforms. Since the opening of the facility, to sustain the facility's performance and reinforce its commitment the new maintenance culture, the operator's policy has been to maintain the facility looking in new condition.

Together, these factors improve the workforce's morale and contribute to a commitment to quality. The agency's recent performance-based maintenance contracts have also helped supported the cultural transition. The operator's fleet managers are responsible for contractor oversight and compliance. The maintenance contract provides a firm standard for performance and ensures the operator's managers can hold maintenance staff accountable to a high standard.

Key Success Factors

- ➢ The department provides requirements and design review for major fleet maintenance facilities construction projects to maximize the facilities' safety and productivity.
- ➢ The agency uses best-value procurements for major facilities construction projects.
- ➢ The department uses cost analysis to support decision-making related to design process, for example to determine which maintenance capabilities are necessary for the facility.

Purchasing and Materials Management

The materials management department's focus is on providing an efficient supply chain service for maintenance and other departments. The materials management department may have other titles, including "Inventory Control," "Inventory Management," and "Procurement." For the purposes of this report, this function is referred to as "materials management." It is the railcar maintenance department's responsibility to determine the materials requirements and manage the materials budget. The purchasing department's responsibility is to meet those requirements at the lowest possible cost and with minimal delay in supplying the part. Materials management manages the internal supply chain and collaborates with the railcar maintenance department to manage inventory levels. The overall goal of materials management is to provide the railcar maintenance staff with the right parts, of sufficient quality and in the right quantity, at the right place and time for an acceptable price (12).

Better management of inventory and purchasing can have the following benefits:

- Lower ongoing inventory cost through fewer overstocked and obsolete items
- Improved vehicle availability through faster repair times
- Reduced material costs through reduced waste of parts, lower freight, and lower procurement cost for parts
- Reduced materials management costs since inventory staff spends less time expediting parts and tracking the progress of high priority orders (13)

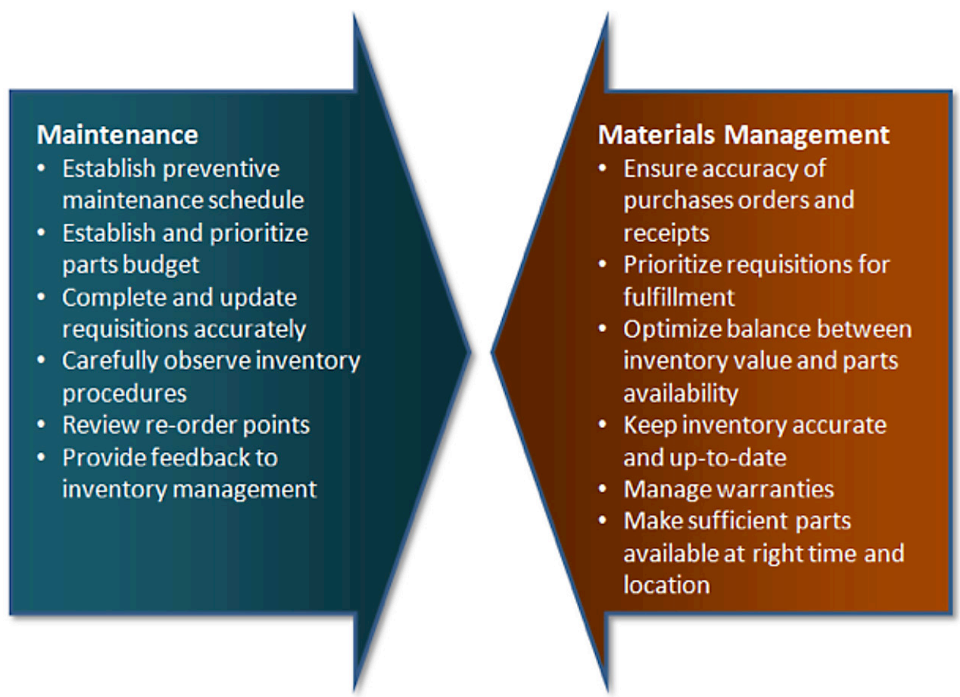
In agencies where the materials management department and railcar maintenance department are separate, these improvements require their close collaboration planning maintenance and managing the supply chain. They also require shared performance improvement processes and effective quality assurance and quality control processes. The following sections discuss each of these topics.

Inventory and Purchasing Roles and Responsibilities

To maintain a successful supply chain for parts, railcar maintenance staff should have actively involvement in materials management. The most important responsibility of the railcar maintenance program is to communicate the expected materials needs, timing, and priorities. Maintenance workers are responsible for completing requisitions accurately, getting proper authorization, and keeping open requisitions updated as needs change. Maintenance, inventory, and purchasing staff must observe all inventory security and record-keeping policies and measures. On the other hand, it is important for materials management to maintain a focus on customer service to the railcar maintenance workers and their support role in railcar maintenance (14). Figure 7-2 highlights each group's responsibilities.

Figure 7-2

Responsibilities of Railcar Maintenance and Materials Management Departments



Frequent planning meetings between maintenance supervisors and inventory/purchasing staff can improve communication and ensure on-time preventive maintenance. A weekly, biweekly, or monthly meeting can cover maintenance campaigns, running rehabilitations, seasonal changes, and preparation for upcoming inspections, so that the inventory department can understand fluctuating parts needs, ensure the parts are on hand, and minimize the possibility of a delay due to parts. Such meetings typically have a standard agenda, which covers routine planning areas, as well as special agenda items to address particular challenges (13).

Inventory Optimization

For a railcar maintenance program that conducts heavy maintenance and uses many thousands of distinct parts over the course of a year, optimization of the inventory requires expertise and analytical capabilities. It also requires effective supporting information systems with materials required identified and their use recorded through the computerized maintenance management system (CMMS). The CMMS must also integrate effectively with the materials purchasing system. Without these elements in place, it is difficult to maintain effective inventory and purchasing functions.

One example of how these elements can be used in materials management is the consideration of risk. For each part needed in the system, the railcar maintenance staff can answer the question "what is an acceptable level of risk related to running out of this part?" For instance, a part whose stock out results in a vehicle remaining out of service likely has a high stock out cost relative to the value of the item and, therefore, requires a conservative stock level and re-order threshold to minimize the risk of a stock out. Such considerations should inform decisions regarding optimal stock levels in the central warehouse and other stockrooms (12).

Close collaboration between the railcar maintenance and inventory functions helps avoid storing excessive parts through joint planning and performance improvement efforts. Weekly or biweekly meetings between the railcar maintenance planners and foremen and materials management staff helps ensure a strong working relationship and good communications channels between the two functions. Having a dedicated analyst supporting purchasing and inventory who can closely track data and perform sophisticated analyses usually generates substantially more savings than the position costs.

Inventory Forecasting

Overall, railcar parts and other materials tend to fall into two major use patterns: predictable use or random use. Items with more random use patterns tend to require relatively higher stock levels all other factors being equal. In either case, efficient management of the inventory relies on accurate forecasting. Maintenance of accurate demand forecasts relies on high quality data from the maintenance management system's inventory component to determine:

- Historical demand: typically the use of parts by week, month, or other timeframe over a fixed historical period
- Lead times based on the typical time from the item request to receipt
- Planned maintenance as communicated by the maintenance department

The inventory function of the MMS should be configured to provide easy access to this information. Based on this information and the ABC classification, the inventory department should be able to determine the re-order point and the economic order quantity (ROP/EOQ). With thousands of items to management, it is useful to have a MMS capability to suggest for ROP/EOQ rules and to rapidly set rules for multiple items based on various selection criteria (13).

Historical inventory and purchasing data can be used to develop control rules for individual items and classes of items. It is possible to develop standard control guidelines for items that exhibit particular characteristics. An item's past and expected use can be used to identify its necessary lead time, its frequency of order, its variability in ordering rate, seasonality factors, its criticality to bus "up time", the availability of the part in the market, and other critical factors. Despite the high number of factors, most items will fall into a limited number of profiles relative an inventory that may contain tens of thousands of items. This modest number of profiles makes it easier to set management rules for large numbers of inventory items.

Inventory QA/QC

Inventory accuracy is critical to ensure proper allocation of material costs, enforce accountability for the use of materials, ensure the delivery of the correct parts, avoid loss or theft of materials, and avoid unexpected stock outs. Moreover, an accurate inventory can best support railcar maintenance activities by minimizing supply chain delays, which can ultimately reduce railcar maintenance costs. This section describes the importance of standardizing parts requests, having an established quality control process for when parts are received, and having effective inventory QA/QC processes.

Standardization is an effective quality assurance tactic for materials management. Most transit agencies have processes in place to put to together a kit, or bill of materials, in preparation for scheduled maintenance and rehabilitations. In fact, these can be created and stored in the CMMS. The railcar maintenance program can use this approach not only for routine preventive maintenance but also for any minor or major maintenance campaign. The maintenance manager shares the scheduled tasks with the parts store, where kits are prepared and delivered in or adjacent to the work station in advance. Such preparation reduces a mechanic's set-up time and increases their productivity. Kits also play a quality assurance role by removing the need for a mechanic to identify and locate the correct part. Inventory staff can take advantage of lower demand shifts to compile kits for preventive maintenance jobs scheduled through the CMMS (10). Performance improvement teams can use processing mapping to further enhance such processes.

Inventory accuracy begins at the receiving end: ensuring items delivered match invoices and are efficiently distributed for end use. For instance, receiving staff can record any inconsistencies between parts ordered and received with respect to accuracy of contents, timeliness, and quality in the CMMS to track vendor performance. For proper cost accounting, each part that leaves the storeroom should be accurately tied to a particular work order and expensed to a particular project or account. This ensures the maintenance department can accurately track the cost of each procedure and its parts requirements. Maintenance workers and inventory staff must work together to ensure accuracy is maintained through the entire internal supply chain until the final use of the part (13), (12).

It is important to have a process in place to follow up on inventory and materials issues such as high levels of inaccuracy found in cycle counts or parts returned by maintenance to inventory. For instance, the former might be an indication that maintenance employees are not adhering to storeroom procedures. The latter example might indicate part quality issues or the placement of multiple orders by maintenance staff because of uncertainty about part availability. Likewise, it is important to make the most of existing QA/QC processes.

Materials Management Process Improvement

ABC classification is one of the most common optimization strategies to organizing inventory items for improved control, minimized parts stock-outs, and reduced ownership costs. The classification system is embedded within the CMMS and used to assign effective inventory control rules to large groups of parts based on shared characteristics. Parts categories can be defined based on several factors: the value of the item's total annual turnover, the frequency of an item's request by maintenance, and the variability of the request rate. Other factors include the lead time for orders, the scarcity of the item, the cost of an out-of-stock event, and the storage requirements for the item. Items within a category will have similar usage patterns. Class "A" items account for the highest proportion by value of the inventory's turnover, and turn over more frequently. Therefore, class "A" requires the most intensive management. Examples of Class "A" items in the railcar maintenance department might include: critical suspension and propulsion components with high value, long lead times, and significant vendor risk. Successive classes (as many as are needed) represent a smaller share of investment and have proportionately lower priority (13), (12).

Higher priority classes benefit more from stricter control measures: more frequent cycle counting, frequent review of demand requirements and re-order rules, and closer tracking of and follow-up on orders. In ABC classification, inventory staff should make stocking decisions first at the commodity level and then at the individual item level only when necessary. Inventory staff can also use ABC analysis to determine whether to stock items at a central warehouse or in local storerooms, using criteria such as lead time and frequency of use to determine the most appropriate stocking location and quantities. It is important to have a process in place for checking the effectiveness of the ABC classification and for regularly updating it (13).

As with other maintenance processes, it is possible to deploy many of the TPM performance improvement methods discussed in Section 3 to the inventory and purchasing functions. For instance, process mapping is a helpful strategy to improve the layout of a storeroom to improve access to frequently-used parts and minimize walking time. Likewise, regular quality circles with inventory staff can help ensure storeroom layouts continue to meet operational needs. Such strategies are critical when a storeroom has limited space: an under-sized storeroom requires more intensive management including more frequent re-order of parts and more reliance on a central warehouse (13).

Predictive maintenance also has implications for materials management and performance improvement. The ABC classification can help determine whether it is worthwhile to rebuild or recondition a part upon its removal from the vehicle. If it is feasible to recondition a part, the next step is to develop an effective testing approach to select parts for reconditioning or disposal (10). If appropriate, such procedures should be embedded in the CMMS as business processes. Such documentation reduces the unnecessary replacement of expensive parts and ensures they enter the proper workflow for reconditioning onsite, at a remote location such as another shop, or at the OEM or another external vendor.

Key Success Factors

- The materials management department effectively prioritizes requisitions for fulfillment.
- The materials management department effectively allocates all materials costs to specific assets and jobs.
- The agency's fleet maintenance planning processes facilitates cooperation between maintenance and materials management staff.
- The materials management department uses ABC classification or a similar strategy to optimize its inventory.
- The railcar maintenance department uses the Total Productive Maintenance approach (or a similar approach such as "Lean Production") in collaboration with materials management staff to realize continuous improvement in the railcar maintenance supply chain.
- The materials management department has effective quality control measures in place to ensure the quality of parts ordered and received and the ongoing accuracy of the inventory.

Information Technology Support

Information systems are foundational for managing railcar maintenance, especially for lifecycle management. High quality IT systems ensure maintenance managers, planners, and engineers have access to comprehensive vehicle data to plan work, schedule work, monitor work performed, vehicle condition, and the lifecycle costs of their assets. IT systems support tracking of maintenance activities, performance management, communication, data and decision analysis, planning and scheduling of maintenance actions and resources, supply chain management, contract management, and data and documentation management (15), (16), (17), (18), (19).

The computerized maintenance management system (CMMS) is the primary management control tool for maintenance. The CMMS may manage a variety of work streams to integrate people, technology, and business processes. CMMSs help manage such complex operations through the following functions:

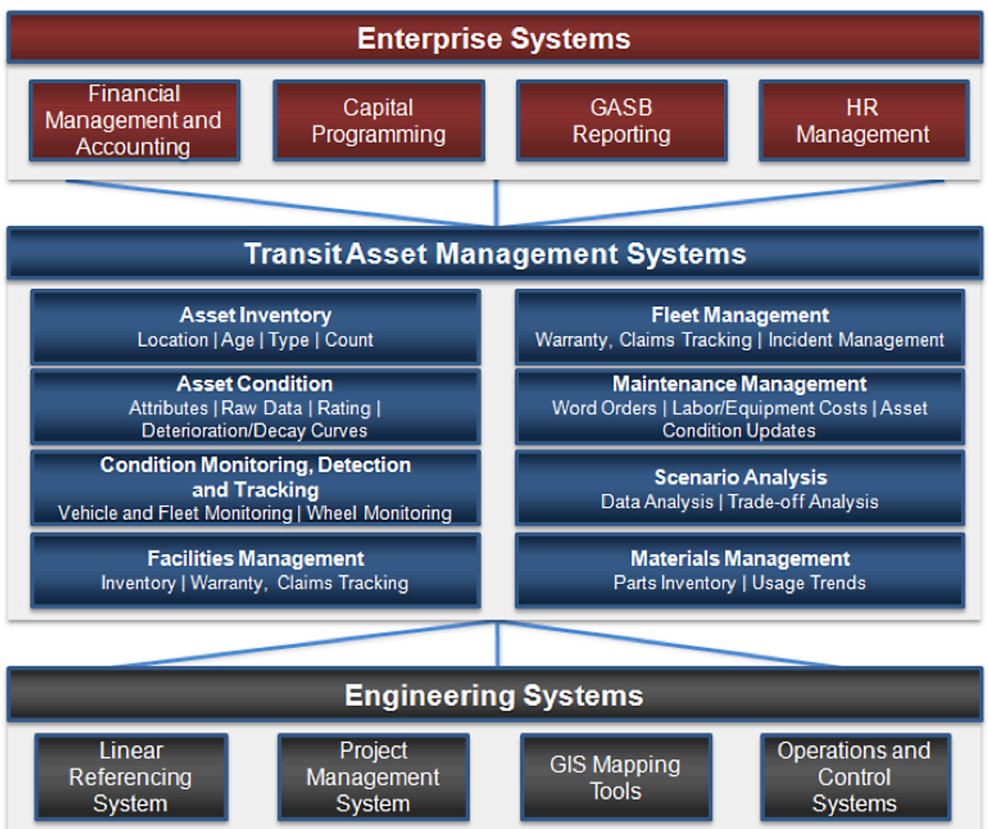
- Resource control – improved accounting for labor, equipment, facility, and other resources
- Cost management – improved cost accounting and reporting
- Scheduling – improved scheduling of complex maintenance operations to better balance work load with maintenance capacity and priority

- Integration – integration of maintenance business processes with other agency business needs and processes
- Performance improvement – continuous performance improvement by providing a framework for collecting data, updating business process, revising documentation, and supporting rapid deployment of other changes in maintenance practices (17), (16)

Currently, the industry is continuing its transition from CMMS to the next generation CMMS/EAM, which has expanded functionalities. For instance, traditionally, most data analysis has occurred outside of the CMMS. However, vendors are increasingly incorporating analytical tools to support root cause analysis, predictive maintenance, lifecycle cost analysis, and risk analysis. CMMS products are also offering more sophisticated planning and scheduling tools, automating and optimizing many of these tasks (20). While newer systems are in many ways much more user friendly, they still require dedicated expertise to maintain business processes and data integrity and to maximize use of the available functionalities (16). Figure 7-3 shows typical agency transit asset management systems and functions within the context of the overall agency information systems architecture.

Figure 7-3

Conceptual Enterprise Asset Management System Architecture



Source: Rose, et al. (22)

Work Order System

The work order system is the heart of the CMMS. It should recommend and record resources necessary for a maintenance job. It should facilitate assignment of appropriate personnel. It should also document steps, methods, tools, parts, and safety procedures for standard jobs and provide access to complete documentation. The work order system should monitor and record the progress and execution of all maintenance tasks. Finally, it should record the most relevant information for analysis of maintenance work to support performance improvement. The work order system should include integration with the materials department to support requisition of parts and tools. The asset inventory links all work orders to specific asses. The CMMS should interface with the ERP to ensure carryover of labor costs, purchasing costs, and other critical cost information to the CMMS to support cost accounting by job and asset (18).

Work orders are generated from maintenance issues, each of which should be assigned a priority level by maintenance managers in order to manage use of maintenance resources. The criticality of a maintenance issue is typically determined by the criticality of the asset and the impact on the vehicle. All maintenance issues and work orders should have a target date for close out based on their criticality. The maintenance schedule provides a comprehensive plan for preventive maintenance jobs for each asset type and individual asset (18).

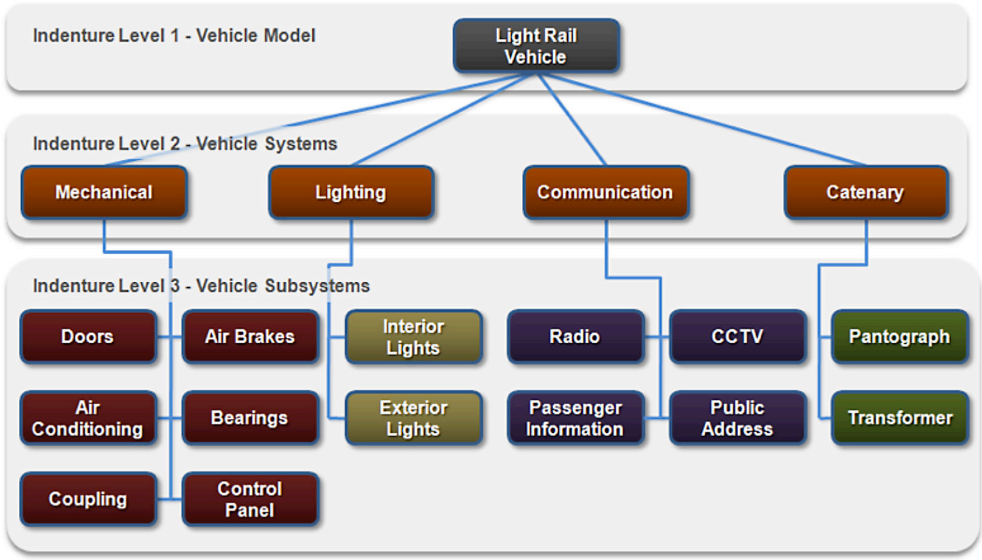
This section stresses the importance of the CMMS's asset inventory as a basis for tracking data, it describes how IT systems can support the railcar maintenance department's performance improvement activities, and it outlines railcar maintenance managers' responsibilities with regards to IT.

Asset Inventory: a Critical CMMS Function

One of the most important features of a CMMS is that it maintains the transit agency's physical asset inventory. Typically, the inventory is hierarchical, starting with the lowest maintainable unit and building up to the high-level asset, in this case a railcar. Therefore, a railcar is made up of various vehicle systems, which in turn may have subsystems and key components. Figure 7-4 provides an example of an asset hierarchy for a light rail vehicle.

Figure 7-4

Example Asset Hierarchy for a Light Rail Vehicle



Source: Adapted from Humphrey et al. (21)

As discussed in the FTA's *Asset Management Guide* (22), the asset inventory includes key descriptive characteristics, such as the component asset tracking identification number, its manufacturer, model number, location (e.g., current vehicle and assigned maintenance facility), and installation date. The asset inventory is the basis for the organization of CMMS's preventive maintenance schedule and its equipment history, which tracks important performance data for vehicle maintenance. Such performance data include past maintenance tasks performed, cost accounting (labor and materials), and inspection and test measurements. These data are the basis for critical vehicle maintenance activities including diagnostics, performance modeling, and condition-based maintenance. The asset inventory process also supports enterprise-level business processes (for example, capital programming and operations and maintenance budgeting).

Another important function of the CMMS's asset inventory is to track critical components over time. Such tracking supports crucial analysis of maintenance effectiveness and the improvement of preventive maintenance. For example, the asset inventory allows a record of bench test results for a particular system. When the historical test results are matched to the assets' work records and compared across assets, it could potentially help the railcar maintenance department to understand the relative quality of different component manufacturers and help improve purchase decisions and parts specifications. Alternately, the same data might help to better time maintenance based on the deterioration of asset performance. Neither analysis is possible without tying the test and work records to specific assets. Therefore, the asset inventory is critical component of railcar maintenance record keeping (23).

Overall, the railcar asset inventory should reflect a level of detail that meets the railcar maintenance program's data collection needs. It is typically most cost-effective to focus on tracking the assets with higher criticality and preventive maintenance requirements. As discussed in Section 4.1, critical components are those with some combination of important business impacts, such as critical safety functions, poor maintainability, and poor reliability. For railcars, this covers a range of assets from air conditioning units to suspension components. It is now standard practice for agencies to require manufacturers to populate an vehicle inventory in the CMMS as part of the delivery process, and the procurement team should participate in the definition of the inventory. The inventory is linked to the preventive maintenance requirements and schedule set up in the CMMS.

Performance Improvement and the Role of IT

As discussed in Section 6, performance management is a data-driven, management control approach to track all activities and investments throughout the railcar's life to ensure that the agency's goals are consistently being met in an effective and efficient manner. Information technology can aggregate data from diverse activities and processes to support performance management and provide workers throughout the railcar maintenance organization with ready access to timely and comprehensive data.

The CMMS work histories can support performance improvement by helping managers understand the performance of individual mechanics and help address issues with training and better assignment of tasks. For example, one transit agency's internal audit of preventive maintenance practices revealed significant number of tasks that had not been completed with quality issues. Because the CMMS was configured to support the tracking of such issues back to the mechanic or team who completed the preventive maintenance inspection, it was possible to follow up on individual issues and ensure individual workers' accountability for such issues (24). At some agencies, each list item in a preventive maintenance inspection requires the sign off of an individual mechanic who is accountable for its proper completion. When a system fails an inspection test or a mechanic identifies a needed repair, these should be entered and tracked in the CMMS. Many agencies use the detailed data collected by their CMMS to benchmark task work times and to account for the cost of individual tasks to support performance improvement efforts.

Integrating Onboard Systems with the CMMS

Increasingly, agencies and vendors are supporting integration between on-board vehicle computer systems and the CMMS. The application programming interfaces (APIs) for late generation CMMS applications can support integration with a wide variety of systems and the collection of more diverse and timely operating data from various vehicle systems (31). Moreover, communications-based train control systems can support direct monitoring of the onboard computer system and relaying of operations data and fault information to the maintenance department in real-time (28). Through the vehicle's onboard computer system, maintenance management systems can capture sensor data from nearly every vehicle subsystem—information such as temperature, pressure, status, and position—which can improve diagnostics and testing. With handheld mobile devices increasingly available to use with maintenance management systems, vehicle maintenance workers can access workstation functions as they physically work on the vehicle, potentially improving effectiveness further (35).

For larger heavy and commuter rail operations, real-time availability of onboard diagnostics along with effective vehicle tracking can provide useful data to support decision-making. Maintenance staff can use the real-time data to increase maintenance operational efficiency, taking railcars out of service if necessary and better prioritizing and routing railcars as they enter maintenance facilities. In some cases, the information lets the maintenance facility prepare for the car's arrival, ensuring a faster repair and improving vehicle availability (35). As new generations of railcars enter service and CMMS capabilities expand and improve, significant opportunities exist to make even more use of onboard computer systems' capabilities. Both maintenance engineers and vehicle procurement teams should collaborate with a CMMS analyst to understand the data generated by critical vehicle subsystems and carefully consider how the information might be logged and reported in the CMMS. Such data can be used to automatically generate work orders and schedule maintenance and support greater use of condition-based maintenance.

Maintenance Managers' IT Responsibilities

Railcar maintenance managers should promote a maintenance culture that is disciplined in its use of the CMMS to preserve the integrity of the system's processes and data. Good data management derives in part from high quality systems and implementation, but it also involves the people who use the tools and are responsible for data accuracy and usefulness. Quality assurance measures include limiting who has access to update the database, or limiting content that can be entered into input fields. High quality data is clearly defined and provides an accurate and up-to-date picture of the operation's status, actions, and resources (16).

The following provides a list of good practices around CMMS usage that railcar maintenance managers can promote:

- CMMS procedures should be clearly established, documented, and communicated.
- All maintenance staff should have a consistent understanding of how to use the CMMS based on regular trainings.
- Managers need to conduct regular spot checks to verify adherence to protocols for use of the CMMS, including reviewing work orders to ensure mechanics and technicians are properly completing work orders and entering information in a timely manner.
- Maintenance managers should promptly address any failures to meet standards, if necessary with training, adjustments to procedures, or modification of CMMS forms.
- Directly enter data into the CMMS, wherever possible. The use of log sheets to document maintenance issues or work results in redundant effort to input data into the CMMS, more data errors, and less timely data.
- Where possible, CMMS forms and business processes should emphasize automatic validation, clear coding of information, and automatically-generated exceptions when tasks and work orders are not properly completed, approved, or closed out in the CMMS.
- To the extent possible, management reports, whether real-time status reports or periodic performance reports, should use the CMMS's automatic query capabilities and rely on data within the system. Reliance on offline tools and data results in less efficient use of managers' time, poorer data quality, and compartmentalization of information (16), (25).

Not following these good practices may compromise the ability of managers to implement performance-based maintenance through the CMMS.

Internal Audit and Quality Assurance

One transit agency's internal audit of its railcar preventive maintenance practices revealed that some preventive maintenance tasks had been signed off on as complete, yet the quality assurance inspections showed no work had been done, required tests were not administered, or that vehicles had not passed an inspection test and the mechanic had not followed up to resolve the issue (24). This example shows how quality assurance inspections are critical for maintaining accountability and revealing labor-related issues before they become systemic.

At another agency an internal audit included a review of a random sample of CMMS work orders and revealed that work orders were not being closed out in a timely manner, were missing essential information on maintenance tasks completed, and had miscoded failure modes. According to the audit, these issues reflect a lack of awareness among frontline employees about proper procedures for use of the CMMS, insufficient commitment to compliance with CMMS work order procedures on the part of some staff, and deficient validation and quality control measures in the CMMS to ensure data completeness, accuracy, and conformance to maintenance procedures (25).

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Key Success Factors

- The railcar asset inventory in the CMMS supports effective tracking of performance and cost of the lowest maintainable unit (e.g., individual vehicle doors, diesel engine transmissions, or critical truck components).
- Managers use the CMMS as the system of record for all management reports related to railcar maintenance.
- The department maximizes the testing, inspection, and onboard computer system data collected in the CMMS to support ongoing performance analysis.
- The department has an analyst to provide ongoing support, improvement, and QA/QC for the CMMS.
- Managers track and enforce employees' adherence to CMMS procedures.

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