FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Transit Asset Management Systems Handbook

Focusing on the Management of Our Transit Investments

SEPTEMBER 2020

FTA Report No. 0173
Federal Transit Administration

PREPARED BY
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U.S. Department of Transportation
Federal Transit Administration

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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13. ABSTRACT

This handbook is intended to expand upon and provide general information and guidance on the management of systems and associated assets used in the transit operating environment in support of the FTA Transit Asset Management (TAM) rule. It offers a framework that outlines systems theoretical concepts and defines specific classes and types of transit systems to foster consistency in transit system asset management practices. Practical information is presented to assist transit operators in their efforts to inventory systems assets and identify activities and investments needed throughout the system life cycle to receive the most value from the system. Neither this handbook nor any of its recommendations are FTA requirements; however, the document provides clarification on associated existing FTA National Transit Database (NTD) Asset Inventory Module (AIM) reporting requirements and makes note of where FTA regulations intersect with the asset management practices discussed herein.

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Abstract

This handbook is intended to expand upon and provide general information and guidance on the management of systems and associated assets used in the transit operating environment in support of the FTA Transit Asset Management (TAM) rule. It offers a framework that outlines systems theoretical concepts and defines specific classes and types of transit systems to foster consistency in transit system asset management practices. Practical information is presented to assist transit operators in their efforts to inventory systems assets and identify activities and investments needed throughout the system life cycle to receive the most value from the system. Neither this handbook nor any of its recommendations are FTA requirements; however, the document provides clarification on associated existing FTA National Transit Database (NTD) Asset Inventory Module (AIM) reporting requirements and makes note of where FTA regulations intersect with the asset management practices discussed herein.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Acknowledgments

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Section 1

Introduction

1 Introduction

1.1 Background

On July 6, 2012, the Moving Ahead for Progress in the 21st Century Act (MAP-21) amended Federal transit law to require the Federal Transit Administration (FTA) to develop a rule establishing a national Transit Asset Management (TAM) System. FTA has defined transit asset management as a strategic and systematic process of operating, maintaining, and improving public transportation capital assets effectively through their entire life cycle. Published in July 2016, the rule:

- Defines "State of Good Repair"
- Requires grantees to develop a Transit Asset Management (TAM) plan
- Establishes standard state of good repair performance measures
- Requires grantees to set state of good repair performance targets based on those measures
- Establishes annual reports requirements to the National Transit Database (NTD)
- Requires FTA to provide technical assistance

More specifically, the rule requires FTA grantees to develop asset management plans for their public transportation assets that should include vehicles, facilities, equipment, and support infrastructure. The infrastructure category in the example of Appendix A to Part 625 includes a stand-alone systems asset class. It also includes other asset classes such as fixed guideway, power, and structures which may fit the definition of systems or be considered part of a broader system of systems[1] framework. (see Appendix C).

1.2 Purpose of this Handbook

This handbook is intended to expand upon and provide general information and guidance on the management of systems and associated assets used in the transit operating environment in support of the FTA TAM rule. It offers a framework that outlines systems theoretical concepts and defines specific classes and types of transit systems to foster consistency in transit system asset management practices. Practical information is presented to assist transit operators in their efforts to inventory systems assets and identify activities and investments needed throughout the system life cycle to receive the most value from the system.

[1] System of systems is a set of systems that integrates or interoperates to provide a unique capability that none of the constituent systems can accomplish on their own.

Neither this handbook nor any of its recommendations are FTA requirements. However, the document provides clarification on associated existing FTA NTD Asset Inventory Module (AIM) reporting requirements and makes note of where FTA regulations intersect with the asset management practices discussed herein.

1.3 Intended Audience

This handbook is intended for any organization receiving FTA funds that owns, operates, or manages transit system assets. Whereas this handbook may be helpful for those who occupy Accountable Executive positions at their agencies, it is directed mainly to those who compile the agency's asset inventory information and conduct or report asset condition assessments, performance measures, and investment prioritization processes. This includes the asset management, operations, planning, budget, and finance staffs of U.S. transit operators. With the understanding that transit systems are complex and their jurisdictions typically span beyond the boundaries of a single department, this document is also aimed at serving as a resource to all systems stakeholders, including users and in-house and contracted personnel involved in the operation and maintenance of systems, as well as all other personnel that sporadically support the viability of systems through their life cycles (for example, procurement, accounting, and environmental departments).

1.4 Handbook Contents Overview

This handbook provides a framework of transit systems definitions and descriptions in alignment with the FTA Transit Economic Requirements Model (TERM) and NTD AIM. The document presents current practices and lessons learned from selected U.S. transit operators regarding transit systems' asset inventorying, performance monitoring and evaluation, and investment prioritization. It also offers insights related to current pressing issues and potential future challenges facing transit systems operators and maintainers.

This handbook was created to complement and support existing FTA guidance documents, such as the *Transit Asset Management Guide*, Facility Condition Assessment and Performance Restriction (Slow Zone) Calculation guidebooks, and the *National Transit Database Policy Manual* (FTA, 2016a, 2016b, 2017a, 2019a).

There are six transit system asset classes in this document. These asset classes are aligned with FTA's TERM, NTD AIM, and Standard Cost Categories used under New/Small Starts:

- Vehicle Control and Signaling
- Traction Power/Electrification
- Communications
- Revenue Collection

- Information Technology (IT) (Business Applications)
- Tunnel Support

This document also addresses the increasingly central role of communications and IT in the operation and maintenance of transit systems. Communications and IT create opportunities to centrally control systems assets and to incorporate real-time monitoring capabilities. These expanded capabilities, coupled with the option to store enormous amounts of data for analysis, allow operators to use them for maintenance planning, investment prioritization, and decision support purposes. The extended use of IT tools is not confined to the transit systems defined herein, but allows operators to create a network and link assets that otherwise operate as stand-alone elements, thus not being part of a system (for example, elevators and escalators).

1.5 Sections Overview

This document is organized into the following six sections:

1) **Introduction** describes the background and purpose of the document, the intended audience, and the scope of information within.
2) **Systems Theoretical Framework** provides a foundational transit-specific systems framework to understand how systems are structured, operated, and maintained.
3) **Overview of Transit Systems** provides an overview of each transit system asset class, networks, and common types of transit systems that consists of a general description of the system, the function(s) it performs, as well as subsystems and key individual assets.
4) **Systems Asset Inventories and Hierarchies** provides direction on how systems assets can be organized and classified in functional groups and subgroups for inventorying and other related asset management purposes.
5) **Systems Performance Management and Investment Prioritization** presents an overview of system performance management, including monitoring and measuring methodologies more commonly used for transit systems. It discusses the resulting impact on the overall system asset life cycle, including operation and maintenance, as well as how systems performance monitoring techniques influence the prioritization of capital investment.
6) **NTD AIM Reporting Guidance** presents supplemental guidance on NTD reporting for currently required systems asset classes (that is, traction power/electrification and train control/signaling systems) outlined in the *National Transit Database Policy Manual*.

1.6 References

FTA. 2016a. *FTA Transit Asset Management Guide (Report 0098)*. Washington, DC: Federal Transit Administration.

FTA. 2016b. *Facility Condition Assessment Guidebook*. Washington, DC: Federal Transit Administration.

FTA. 2017a. *TAM Infrastructure Performance Measure Reporting Guidebook: Performance Restriction (Slow Zone) Calculation*. Washington, DC: Federal Transit Administration. April.

FTA. 2018. *TAM Facility Performance Measure Reporting Guidebook: Condition Assessment Calculation*, Version 1.2. Update Appendix B. Washington, DC: Federal Transit Administration. March.

FTA. 2019a. *National Transit Database 2019 Policy Manual: Full Reporting*. Washington, DC: Federal Transit Administration, Office of Budget and Policy.

Section 2

Systems Theoretical Framework

2 Systems Theoretical Framework

This section provides a foundational overview of a theoretical framework applicable to systems. These basic concepts are expected to serve as a starting point for an enhanced understanding of transit systems in the context of the processes and engineering activities needed to ensure the systems' viability through their life cycles. The systems theoretical framework used in this handbook is based on systems concepts included in ISO/IEC/IEEE 15288:2015, *Standard for Systems and Software Engineering—System Life Cycle Processes*; the International Council on Systems Engineering's (INCOSE's) *Systems Engineering Handbook*; and NASA's *Systems Engineering Handbook* (Revision 2). All systems concepts referenced in this handbook were selected based on their relevance to transit and rail operating environments and to establish a common understanding of a system structure and its boundaries.

2.1 What Is a System?

A system is an organized set of interacting parts capable of performing one or more stated functions or behaviors that no one subset of parts has. Systems are constructed "… and utilized to provide products and/or services in defined environments for the benefit of users and other stakeholders" (ISO/IEC/IEEE 15288:2015, p. 11). The system is composed of an assortment of subordinate systems (subsystems) and system elements that may be located throughout the owning entity's service area. To operate as required, a system must fulfill the following key requisites at a minimum:

- All critical subsystems and system elements must be set in place and function as required.
- All critical subsystems and system elements must be linked (or ready to be linked when required).
- All critical subsystems and system elements must interface and interact among themselves as designed and required.

Following are three closely-aligned definitions of a system recognized within the field of systems engineering:

- "A combination of interacting elements organized to achieve one or more stated purposes" (ISO/IEC/IEEE 15288:2015, ISO/IEC/IEEE 12207:2017).
- "An integrated set of elements, or assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware),

processes, people, information, techniques, facilities, services, and other support elements" (INCOSE [2015] *Systems Engineering Handbook*).

- "The combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose; that is, all things required to produce system-level results" (NASA [2016] *Systems Engineering Handbook*).

In the context of transit operations, a transit system is defined as an organized set of interacting parts capable of performing one or more stated functions. Parts include infrastructure, electrical and/or mechanical equipment, hardware, software, information, personnel, processes, procedures, and other support components required to perform one or more stated functions.

This handbook focuses on the management of physical assets of transit systems, such as infrastructure (antennas, cables, and data center buildings) and electrical and mechanical equipment (transformers and signal switches), hardware (servers, routers, and network switches), and software (that is, business applications). However, additional system support elements such as personnel, processes, and procedures are critical elements contributing to the existence of these systems and must be considered when establishing the viability of these systems through their entire life cycles.

2.2 System Structure

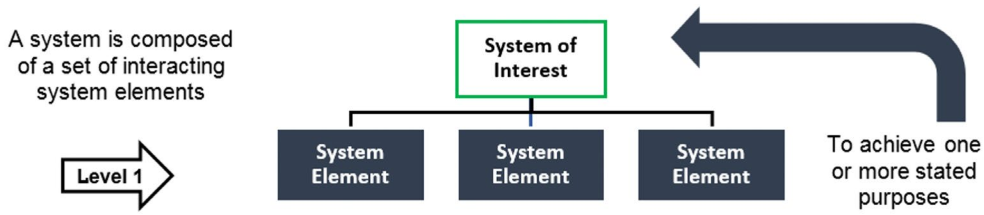
The system structure is a top-down decomposition of the system's physical objects until single parts (elements) are reached. System elements can be either an individual element (a single asset) or a group of like elements (group of same assets), but are regarded as "atomic," or parts that cannot be further decomposed. From an asset management perspective, system elements can be considered atomic when they represent the lowest maintainable unit of a system, or the level at which decisions to maintain, inspect, rehabilitate, or buy systems assets occur. All system structures will have only system elements at the lowest level.

The system structure can be considered an asset hierarchy of the simplest kind, focused only on grouping and decomposing the physical parts of the system. For systems asset management purposes, more complex and multidimensional hierarchies that further organize assets by attributes like location, type, owning department, or identification number will prove more useful and informational in maintaining the system as they reflect the system function, expanse, and operation. Creating an asset hierarchy for life cycle asset management purposes is discussed in detail in Section 4.

Figure 2-1 shows a very simple single-level system structure. This basic system structure has no subsystems and is composed of a set of three interacting elements, all of which contribute to provide the predetermined system's functioning requirements and represent single parts that are lowest maintainable units of the system.

Figure 2-1

Simple Single-Level System Structure



More complex systems may have components that are systems themselves, as in a system of systems, and that can have additional subsystems or system elements. Figure 2-2 shows a complex, four-level system structure. The components shown in Levels 1, 2, and 3 are a combination of subsystems and system elements. As the lowest level, Level 4 is composed of system elements only and therefore there is no further breakdown.

As an example of how this theory of basic system structure can be applied to transit systems, Figure 2-3 depicts a four-level structure for a generic closed-circuit television (CCTV) surveillance system. At Level 1, there are three subsystems (Control Center, Network, and Cameras on Location). Levels 2 and 3 include additional subsystems as well as system elements. At Level 2, the Cameras on Location subsystem is divided into groupings of like assets (that is, Analog Cameras and IP Cameras) that are one of the lowest maintainable units of the CCTV system. Level 4 includes only system elements. Some of these system elements may represent a single asset or a grouping of similar assets, but all represent assets that are considered lowest maintainable units of the CCTV system.

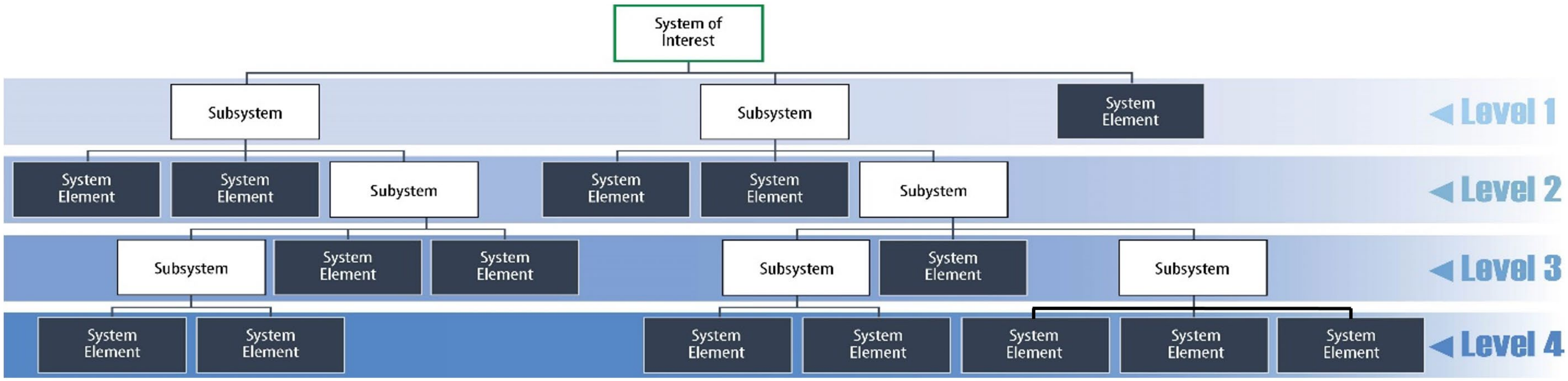
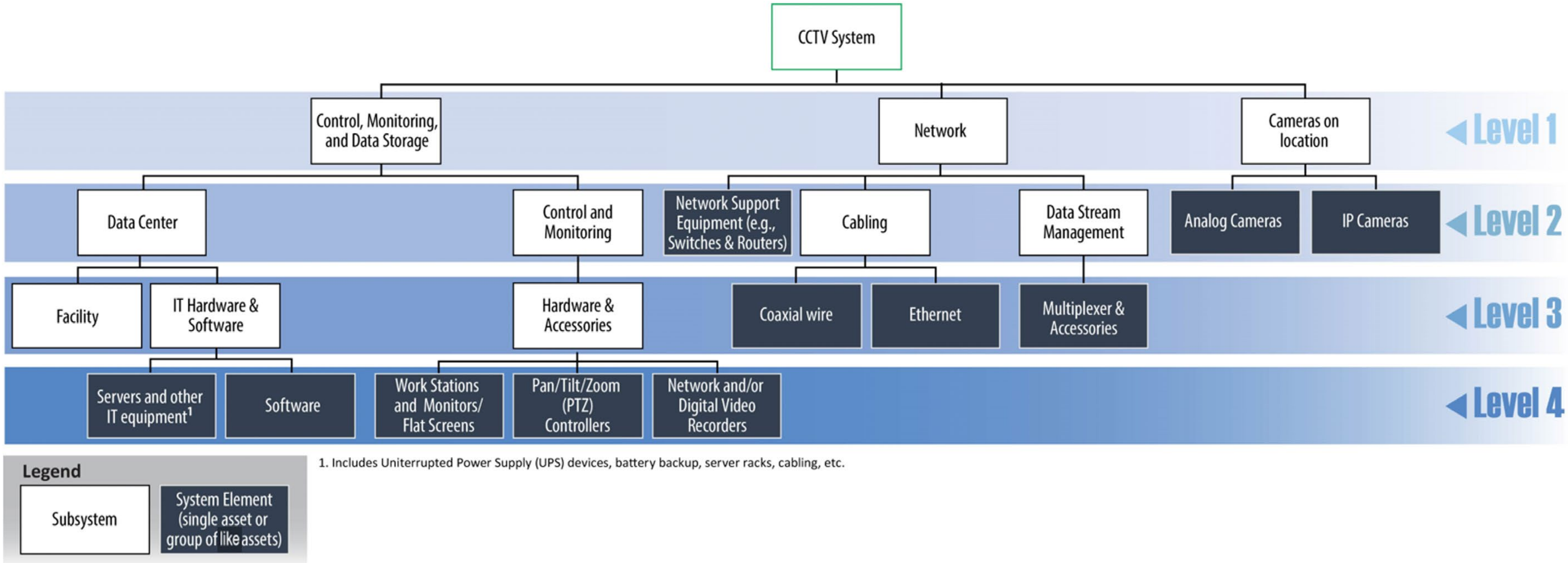


Figure 2-2 *Complex Four-Level System Structure*



1. Includes Uniterrupted Power Supply (UPS) devices, battery backup, server racks, cabling, etc.

Figure 2-3 *Example of an Integrated CCTV Surveillance System*

2.3 System Boundaries

A system boundary is "a 'line of demarcation' between the system itself and its greater context (including the operating environment). It defines what belongs to the system and what does not" (INCOSE, 2015, p. 6). This is an area of critical importance to rail and transit operators given the enormous amount of activity between parallel systems that share functions and services. In the case of a rail operator for example, a power system that provides energy to a train control system needs to have its boundaries clearly delineated by defining where the power system ends and where the train control system begins. Similarly, a fiber-optic network can simultaneously support a train control system and several communications systems. To avoid the risk of double counting assets or to eliminate gray areas (where there is no defined operational or maintenance responsibility for the assets in question), transit agencies will benefit greatly from establishing clear lines of demarcation among their systems.

2.4 System Architecture

The system architecture incorporates the basic system structure and boundaries into an abstract, functional description or graphical representation of the arrangement of parts of a system, such as physical and information elements, and the relationships (informational, temporal, geometrical, energy exchange, etc.) and interfaces between those entities (Crawley et al., 2004). Architecture conveys system behavior, and the interactions of form, functions, and constraints, within the broader context or environment of the system. Every system has an architecture, an embodiment of the allocation of physical or informational function to the elements of the system through relationships and interfaces, all within the context of the surrounding system environment. The architecture conveys the system behaviors, which are the products of these relationships and interactions between the system elements, whether designed or unanticipated.

Architecture is necessary for system design. Creating an architecture involves determining what the system is supposed to do and how. Some system architectures are carefully and thoughtfully developed and set during the system design process. Larger, more complex systems may have an evolving architecture, especially if the system grows by accretion or incorporation of smaller systems.

Systems can have multiple representations or architectures depending on how the systems boundaries are defined. Several types of architectures as defined by Crawley et al. (2004) are described below; typically, a system has both a physical architecture and numerous virtual architectures (functional, technical, etc.) to capture important aspects or perspectives of the system behaviors:

- **Physical architecture**: At a minimum, a visual representation of physical resources and their interconnections using nodes (element or subsystem boxes) and connecting lines (can be as detailed as a system structure or asset hierarchy, or depict higher level groupings of resources).

- **Functional architecture**: A partially ordered list of activities or functions needed to accomplish the system's requirements.
- **Technical architecture**: An elaboration of the physical architecture that comprises a minimal set of rules governing the arrangement, interconnections, and interdependence of the elements, such that the system will achieve the requirements.
- **Dynamic operational architecture**: A description of how the elements operate and interact over time while achieving the system's goals.

A depiction of a comprehensive system architecture is instrumental in providing a complete view of the system and the interaction of all essential subsystems and system elements necessary for operation. This can be particularly helpful when defining the parameters needed for the creation of systems asset hierarchies for the purposes of systems asset management (discussed further in Section 4). Having a system architecture that segments system elements by location, how easily they can be controlled or observed, or how they are best operated or repaired rather than by what they do or how they were designed can help create a useful asset hierarchy and help users or operators better manage a complex system.

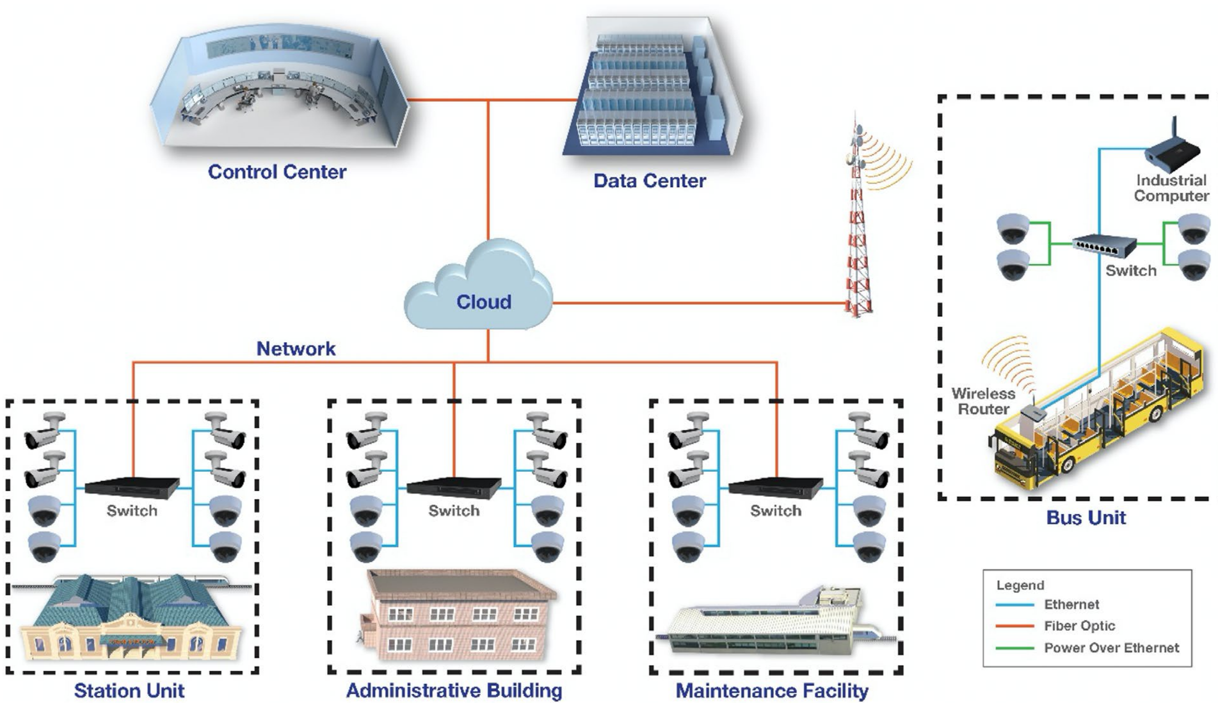


Figure 2-4 *Generic CCTV System Architecture*

2.5 System Life Cycle Stages

A life cycle is the series of stages through which a system (or asset) passes. The implementation of a system requires extensive planning and coordination throughout and between life cycle stages to optimize resources. For example, during early concept and development stages, the needs of subsequent stages must be carefully studied, analyzed, and accommodated by appropriate decisions regarding cost constraints and technical challenges. This subsection presents the life cycle concepts and theoretical framework included in the INCOSE (2015) *Systems Engineering Handbook*, founded on ISO (2010) (ISO/IEC TR 24748-1, Systems and Software Engineering—Life Cycle Management—Part 1: Guide for Life Cycle Management), and ISO/IEC/IEEE (2015) (*Systems and Software Engineering—System Life Cycle Processes*).

"The purpose in defining the system life cycle is to establish a framework for meeting the stakeholders' needs in an orderly and efficient manner for the whole life cycle." (INCOSE, 2015, p. 25).

A system life cycle consists of the following main aspects:

- Business (business case)
- Budget (funding)
- Technical (product)

For the system to be successful, it is imperative to create technical solutions that are consistent with the business case and encapsulated within the funding constraints of the initiative. System integrity requires that these three aspects are in balance and given equal emphasis as part of decision-making processes during implementation of the project.

A system progresses through its life cycle from inception to concept, development, production, use, support, and final retirement.[2] The life cycle model is the framework that helps ensure that the system meets its required functionality throughout its life. Figure 2-5 shows the six stages in the system life cycle moving from left to right. Although the stages on Figure 2-5 are shown as independent, nonoverlapping, and serial, the activities of these stages can in practice, be interdependent, overlapping, and concurrent.

[2] According to ISO/IEC/IEEE 12207:2017, the use of these six stages is not normative. It further indicates that a common set of stages for a software system is concept, exploration, development, sustainment, and retirement, with transitions between stages for the system as a whole and for its elements.

Figure 2-5 *Generic System Life Cycle Stages*

Concept Stage: The project starts with a recognition for the need of a new or improved system. In many industries, exploratory research is applied to study new ideas and/or enabling technologies and capabilities during this stage. It is crucial in this stage to identify potential challenges (such as unproven technologies, interoperability concerns, extreme complexities, etc.) to avoid recalls and rework in later stages. This stage evaluates the stakeholder needs, but also the organizational capabilities needed to successfully implement the project. Special importance is given to identify technological risks and to assess the technology readiness level of the project. At this stage, it is imperative to establish what is possible and what is not. The early identification of a preliminary concept and enabling technologies helps system designers to get a head start addressing issues. The preliminary concept will also be used to generate early cost and schedule projections for the project. Key outputs from exploratory research can include the following:

- Clearer understanding of business or mission requirements and stakeholder needs
- Alignment to agency's purpose and objectives
- Assessment of technology readiness
- Rough estimate of the project cost, schedule requirements, and technical feasibility

Of critical importance is to ensure that all efforts are in alignment with the agency's purpose and objectives. At this stage, a more in-depth evaluation of the stakeholder's conceptual operation of the system and operating environments takes place. Detailed studies of multiple candidate concepts will result in substantiated justification for the selected concept. "As part of the evaluation, mock-ups may be built (for hardware) or coded (for software), engineering models and simulations may be executed and prototypes of critical elements may be built and tested" (INCOSE, 2015, p. 30). Studies expand the evaluation of risk and opportunity to include assessment of affordability, environmental impact, and system disposal. An important consideration for this stage is to learn from past experiences. "Many commissions reviewing failed systems after the fact identified insufficient or superficial study in the concept stage as a root cause of failure" (INCOSE, 2015, p. 31).

Development Stage: The development stage defines and realizes a system capable of meeting stakeholders' requirements and can be produced, utilized, supported and retired. This stage initiates using outputs from the concept stage (for example, system of interest, prototypes, enabling systems requirements). During this stage, the business mission needs and stakeholder requirements are converted into system requirements used to create a system architecture and design. Hardware and software elements are built and coded. "One of the key activities of the development stage is to specify, analyze, architect, and design the system so the system elements and their interfaces are understood and specified" (INCOSE, 2015, p. 31).

Production Stage: This is the stage where the system is produced, manufactured, integrated, and made fully operational. Changes to reduce production costs or enhance product or systems capabilities may influence system requirements and may require reverification and revalidation. All such changes require a systems engineering assessment before changes are approved.

Utilization Stage: This is the stage where the system is fully operational and functioning in its intended environment to deliver its intended services. System enhancements or modifications should be assessed by a coordinated effort that may involve systems engineers, asset management practitioners, and operations and maintenance personnel to ensure smooth integration with the operational system.

Support Stage: This stage runs concurrently with the utilization stage (see Figure 2-5). During this stage, the system receives maintenance support to enable continued operation. Modifications may be proposed to resolve supportability issues, to reduce operational and/or maintenance costs, or to extend the life of a system. Such changes can be aided by systems engineering support to avoid the loss of system capabilities while in operation.

Retirement Stage: This is the stage where the system and its related services are removed from operation. Planning for retirement is part of the system definition during the concept stage.

2.6 Enabling Processes and Procedures

Enabling processes and procedures are external activities that are not part of the operational environment of the system of interest but have an important participation during specific periods in its life cycle. Examples of enabling processes and procedures include logistics support activities, budgeting and capital planning activities, and training activities. Figure 2-6 shows the direct interaction of systems within the operational environment of a rail operator, as well as enabling processes and procedures outside this environment. The diagram depicts a traction power/electrification system interfacing continuously with several communications systems, a train control system, and a revenue collection system. On the right side of the diagram are three enabling activities outside the operational environment that contribute to the viability of the traction power/electrification system only during specific periods of its life cycle.

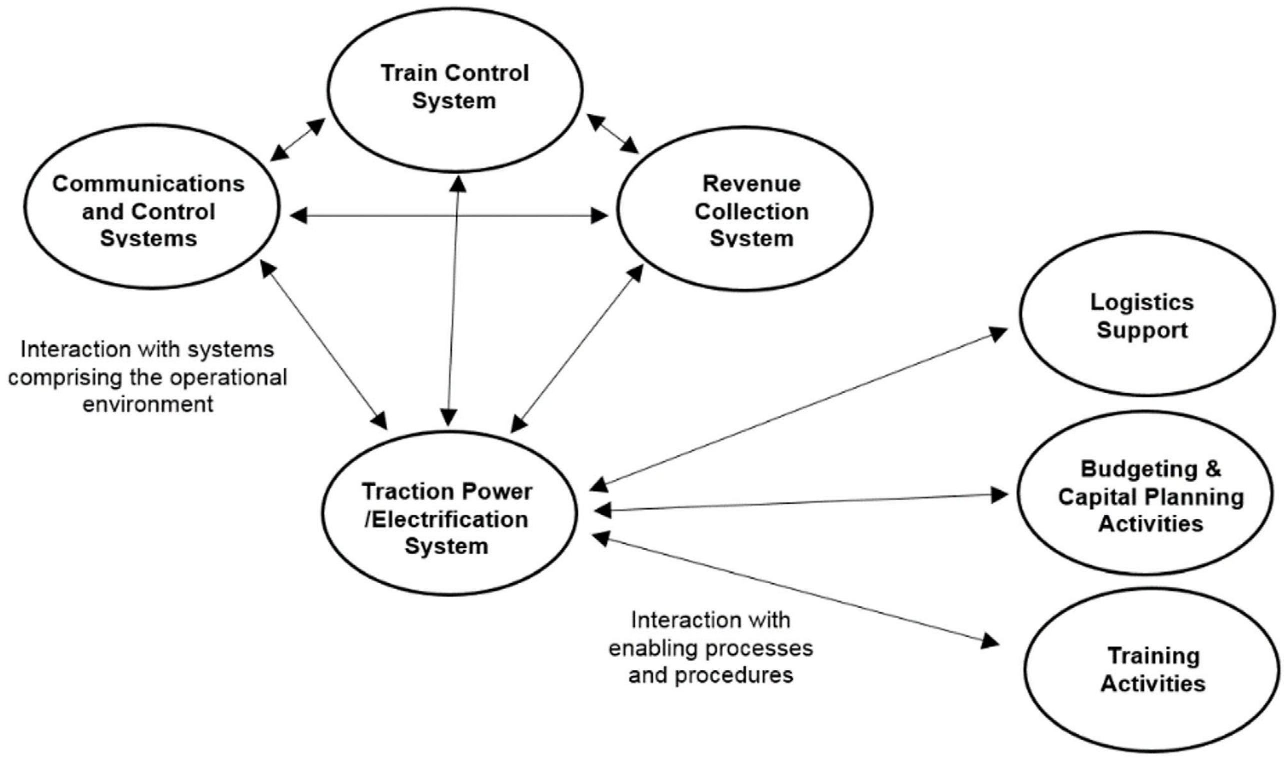


Figure 2-6 *Interaction of Rail Traction Power/Electrification System with Systems in Its Operational Environment and Separate Enabling Processes and Procedures*

2.7 Systems in the Context of Asset Management

Asset management activities account for the larger context of the operating environment in which a system (and all assets within) functions. Establishing protocols for cooperation between the system operations and maintenance teams and the asset management team has the potential to bring enormous benefits to both sides. This cooperation connects the system teams to the broader organizational and operational environment of the agency, including the agency's goals and objectives, and the asset management team gains vital technical insight into current and future operational and maintenance conditions affecting the system life cycle.

Figure 2-7 shows the framework of IAM's Asset Management Model and highlights the subject group modules that contribute to make a system and its assets viable while aiming to obtain the most value for the transit agency and its customers. The application of asset management basic principles ensures activities that support system operations are aligned with the agency's strategic plan. The operation and maintenance of systems as well as the implementation of asset management programs is dependent on people; therefore, their knowledge, competence, and teamwork capabilities will reflect on the asset management outcomes and overall systems operational efficiencies during their life cycles. Asset information serves as the foundation for improved asset management decision making, life cycle delivery, and risk evaluation activities. Asset management decision making activities help shape high-level strategy and planning activities which together with risk and review activities feed back into the asset's life cycle delivery activities.

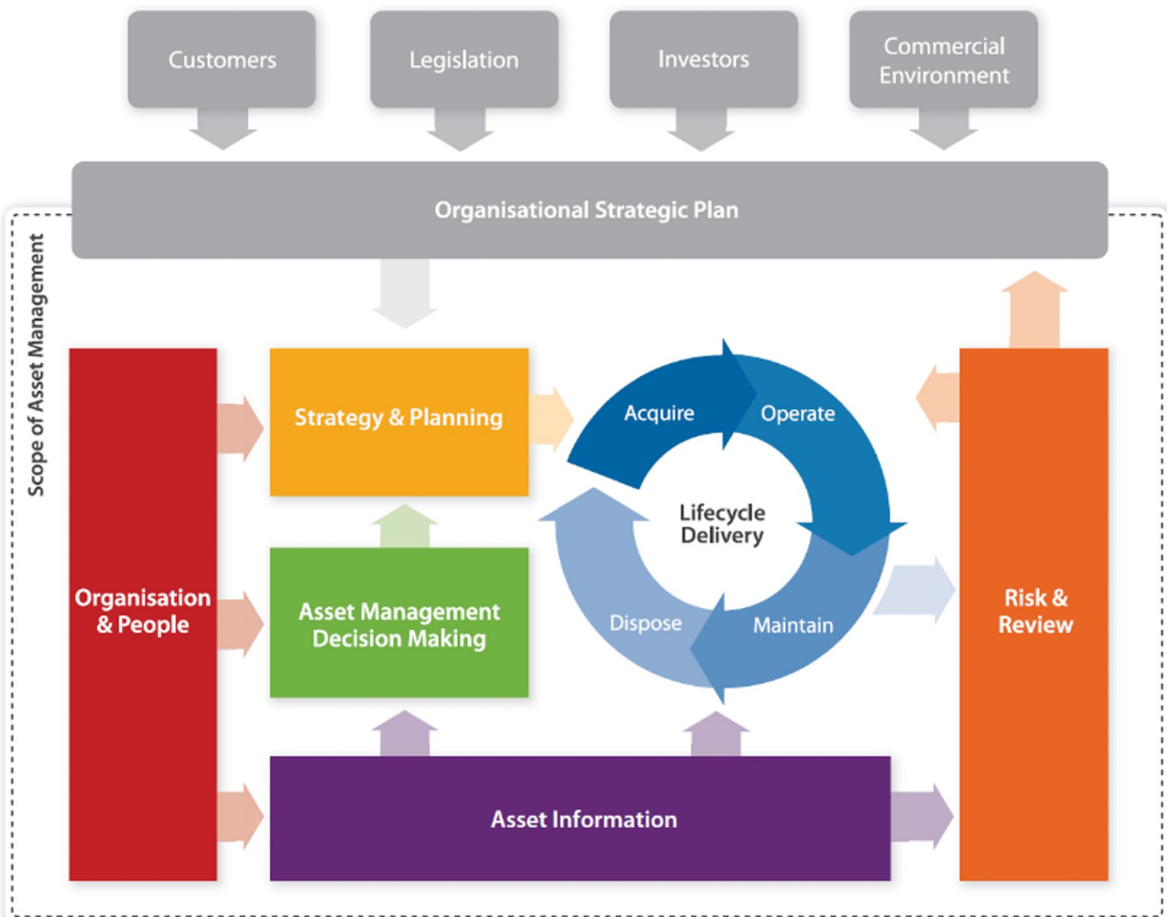


Figure 2-7 *IAM's Conceptual Asset Management Model*

2.7.1 Asset Management Strategy

In alignment with the agency's organizational strategic plan, the asset management strategy lays out the agency's long-term approach to managing its assets (and all systems they support). It further establishes how organizational objectives are to be converted into tangible asset management objectives. The objectives define what the agency aims to achieve from applying asset management initiatives. This includes, but should not be limited to, future capabilities and performance requirements of assets, asset systems, and the entire asset portfolio. The objectives should be Specific, Measurable, Achievable, Realistic, and Time-bound (SMART). The asset management strategy further describes how the agency will develop and improve its capabilities and asset management system (its processes, information, systems, people, tools, resources, etc.). The asset management strategy may include functional strategies to address specific activities (for example, capital programming, operations, maintenance) and asset classes (IAM, 2015b).

2.7.2 Convergence of Systems and Asset Management

Good asset management practice uses a holistic approach to operating and maintaining systems. Assets can be managed with or without a structured organizational strategy, but value is gained from managing assets within a context of organizational purpose and strategy (ISO, 2017), whereby the broader focus of asset management departs from narrowly-focused *managing assets* activities and takes a higher-level perspective that encompasses the entire organization and spans entire asset life cycles. This aligns seamlessly with the systems approach to managing assets. Table 2-1 contrasts simply managing assets with a broader and more comprehensive asset management vision.

Table 2-1

From Managing Assets to Asset Management

Managing Assets	Asset Management
Daily service	Long-term performance
Age	Condition and risk
Up-front cost	Whole-life cost
Maintenance	Life cycle management
Local expertise	Integration
Reactive	Proactive

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Section 3

Overview of Transit Systems

3 Overview of Transit Systems

This section presents a transit systems taxonomy, a controlled vocabulary for classification purposes and for developing hierarchical structures. It also provides an overview of the six transit system asset classes included in this handbook and the most typical or significant types of systems within those six classes. For each system class and type, information is provided on overall system function, typical applications in transit operations, and key subsystems and system elements for asset management purposes.

3.1 Transit Systems Asset Classes

The transit systems taxonomy, or overall classification framework, including the six asset classes, associated networks, and common system types, is depicted in Figure 3-1. Six systems asset classes have been identified to categorize transit systems in alignment with transit agency operations and organization, as well as TERM, the NTD AIM, and the Standard Cost Categories used under New/Small Starts. (Appendix E shows a crosswalk of the systems classification framework with TERM, NTD AIM, and Standard Cost Categories.) Table 3-1 lists the six transit systems asset classes included in this handbook, the general functions provided by the types of systems within the class, and examples of physical system elements (including software).

Table 3-1

Overview of Transit Systems Asset Class Functions and Elements

System Class	General Function	Example System Elements
Vehicle Control and Signaling	Control the movement of vehicles (primarily trains) from origin to destination safely and reliably	• Infrastructure (signal bungalows and housings) • Equipment and hardware (signals, communications kits, interlocking switches, wayside and onboard detection and surveillance devices, and cables) • Software, communications network
Traction Power/ Electrification	Provide electricity for vehicle propulsion and other vehicle-based electric devices (may also supply other service power)	• Infrastructure (catenary poles, duct banks, substation facilities) • Equipment and hardware (transformers, rectifiers, cables, overhead contact lines or third rail) • Software, communications network
Communications and Control	System control, collection of information, and transfer of data through a communications network	• Infrastructure (radio antennas) • Equipment and hardware (cameras, telephones, public announcement, radios, digital display units, workstations, servers, switches, and routers) • Software, communications network
Revenue Collection	System control, collection of information, and transfer of data for the purposes of collecting passenger revenue	• Equipment and hardware (fare vending machines, fare gates, workstations, servers, switches, and routers) • Software, communications network
IT/Business Applications	System control, information collection, and transfer of data through communications network to support a variety of business applications	• Equipment and hardware (workstations, servers, switches and routers) • Software (enterprise asset management, payroll, crew management, and budget and financial forecasting) • Communications network
Tunnel Support	Control and monitor infrastructure support systems, such as tunnel ventilation and lighting	• Infrastructure (ducts and tunnel shafts) • Equipment and hardware (fan plants, power cables) • Software, communications network

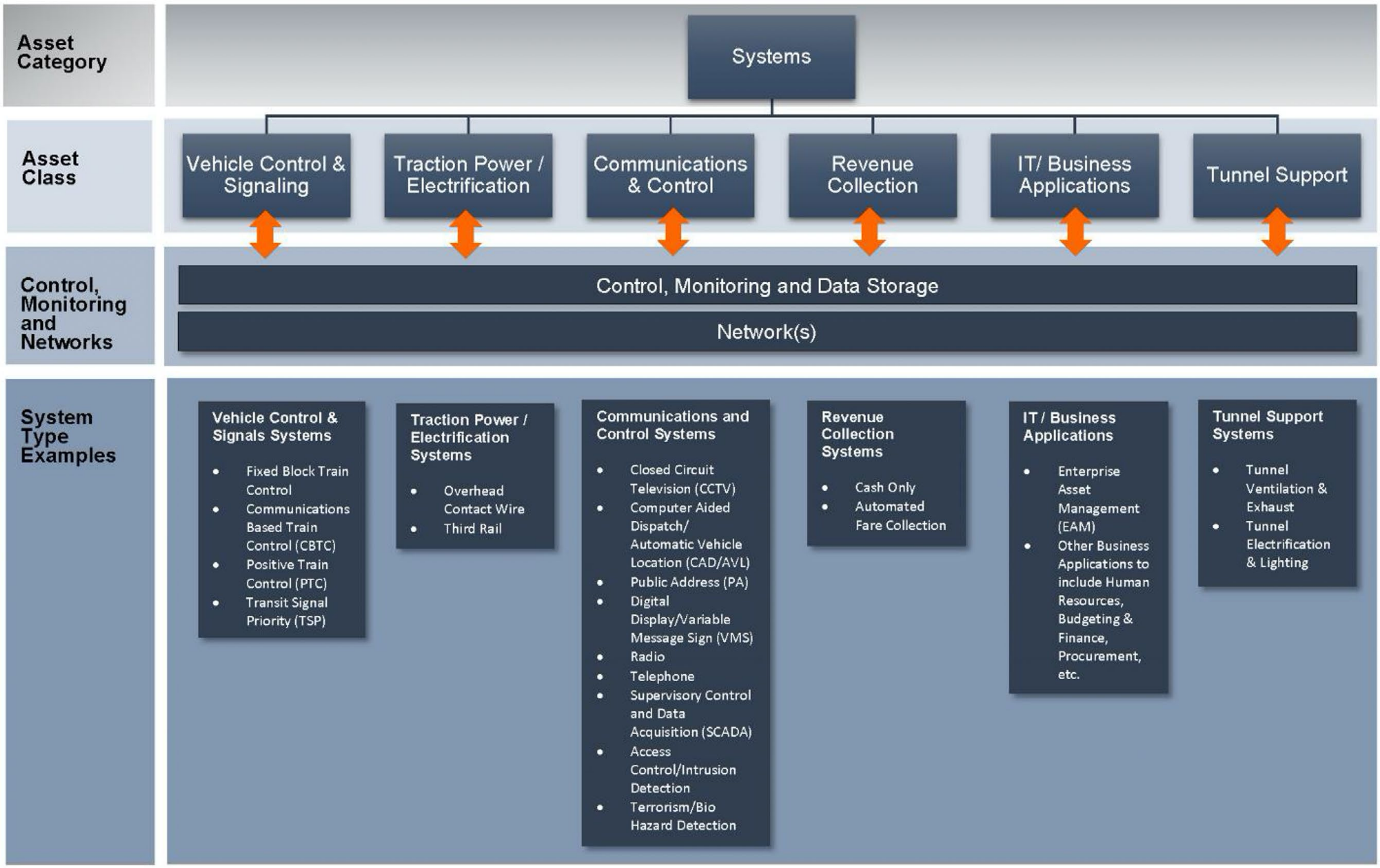


Figure 3-1 *Transit Systems Taxonomy*

3.2 Systems Not Included in This Document

This handbook presents an operational focus on systems with elements dispersed across large segments of a transit operator's service area. As such, building systems that support and are confined to individual facilities are not included. The *TAM Facility Performance Measure Reporting Guidebook* (FTA, 2018), produced to assist transit agencies in determining the condition of their administrative, maintenance, and passenger and parking facilities, identifies multiple building systems that factor into the overall condition of the facility, including the following:

- Conveyance (elevators and escalators)
- Plumbing
- Heating, ventilation, and air conditioning
- Fire protection
- Electrical

The advent of communications networks that can connect stand-alone building systems or assets at individual facilities has created new opportunities for centrally controlling, monitoring, and evaluating building systems, such as elevators or fire life safety systems (see Appendix G for an example). These connected technologies provide advantages associated with managing a network of building system assets as opposed to disparate, individual, and isolated building systems. Whereas connected building systems do not necessarily have the large-scale interdependencies of the transit systems discussed in this handbook (for example, the design and performance of one furnace or elevator does not necessarily impact those at another facility), transit agencies may find a benefit in applying systems asset management practices to connected building systems.

Although location-specific revenue collection assets are tied to a facility for condition assessment purposes as outlined in the *TAM Facility Performance Measure Reporting Guidebook* (FTA, 2018; referenced within as Fare Collection), these assets would benefit from being accounted for in a revenue collection system asset hierarchy. There are no inventory requirements for facility-specific revenue collection assets under the aforementioned Facilities Guidebook.

3.3 Networked Support Systems

The transit systems included in this handbook are networked systems that increasingly rely on communications and IT infrastructure. The system elements of transit systems, which may be located throughout a large service area (along the right-of-way, within stations, administrative buildings, maintenance facilities, garages, and moving vehicles) need to be all linked to be operational. The network is the medium by which the system elements are linked.

The network also connects the transit systems for end-use operations to system elements with control, monitoring, and data storage capabilities. Figure 3-2 presents a high-level, generic physical architecture for networked systems. The systems for end-use operation (bulleted items on the right) include types of transit systems that provide primary functions to support end-use operations. (These transit systems are discussed in more detail in Section 3.4.) If the system requires a network to function, it would connect to a data network that links the system-to-system elements with control, monitoring, and data storage capabilities (box on the left). It is possible for several systems for end-use operations to use a shared network. Figure 3-2 focuses on physical assets of a system but also highlights the physical location of the software (virtual asset) due to its critical importance to the overall system function.

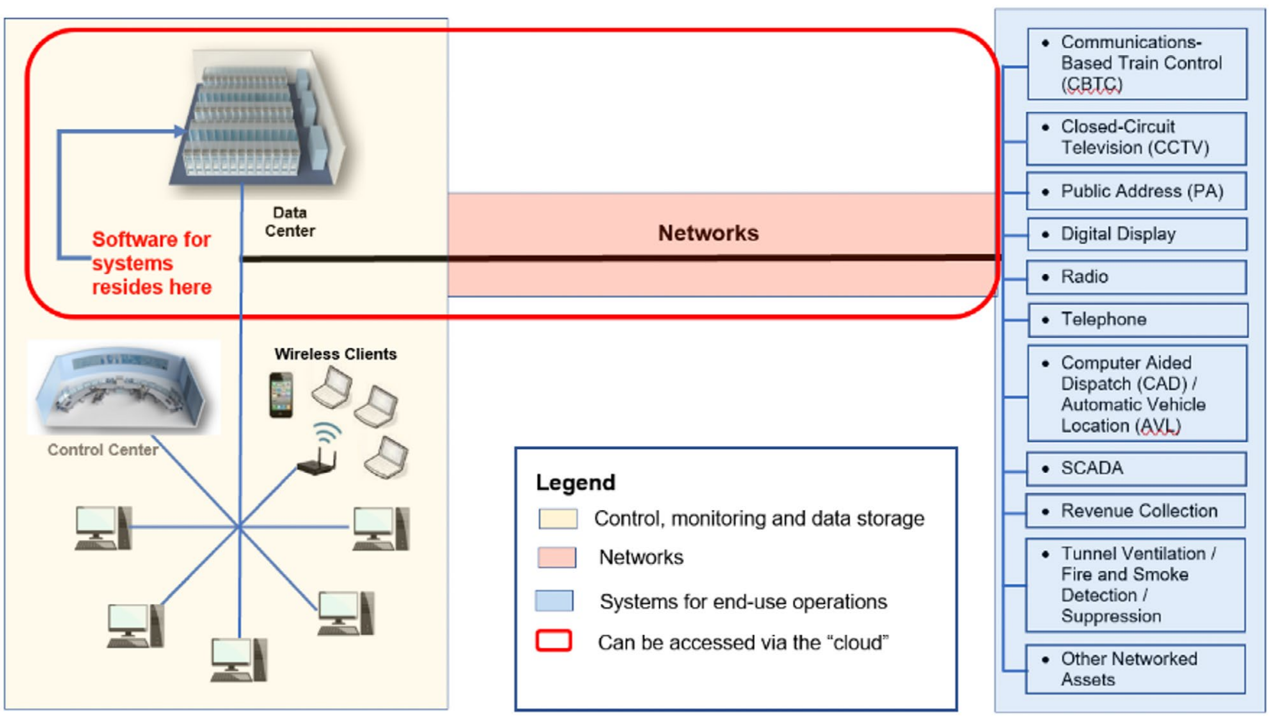


Figure 3-2 *Generic Physical Architecture for Networked Transit System Asset Class Types*

A high-level description and/or examples of the three main groups depicted in Figure 3-2, and a description of cloud services is provided below:

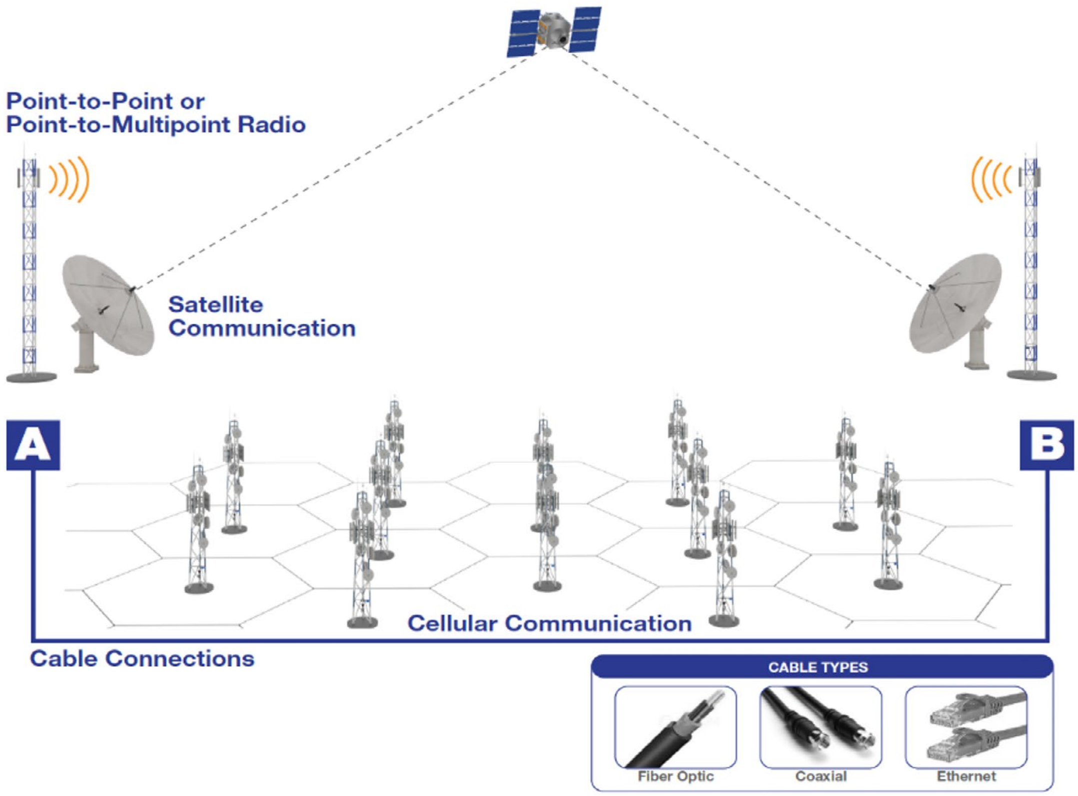
- Systems for end-use operations (bulleted items on right in Figure 3-2): These are systems dedicated to fulfilling specific transit operations functions: for example, a CCTV system records and transmit video images for security, monitoring and surveillance purposes, and a public address (PA) system enables transit operators to transmit audio communication to customers.

Individual system elements of transit systems for end-use operations (bulleted items on right in Figure 3-2) can link to the network at multiple locations. For example, cameras, public address speakers and digital display units connect to the network at each station along the right-of-way of a subway or commuter rail operator. Likewise, similar devices within moving vehicles connect to the network via wireless communications networks.

- **Control, monitoring, and data storage** (box on left in Figure 3-2): This grouping may include the following key system elements: a data center and its servers, a control center, wired clients (individual workstations) and wireless clients (laptops, tablets, and phones). System elements in this group are linked by an internal network (Ethernet, coaxial, fiber-optics, or Wi-Fi). A server is a computer or system that provides resources, data, services, or programs to other computers, known as clients, over a network. In theory, whenever computers share resources with client machines, they are considered servers. Servers are often housed in a data center (a room or building) supported by critical complementary systems such as power supply, ventilation and cooling, fire suppression, access control, and uninterrupted power supply (UPS) systems to ensure uninterrupted power.
- **Networks** (center top area in Figure 3-2): This medium connects the control, monitoring, and data storage system elements with the networked systems. Networked systems commonly have their subsystems and system elements dispersed throughout the agency's service area, which in some cases might be many miles away from the agency control center. Figure 3-3 shows selected network options available to link system elements located throughout the transit agency service area. Note how systems can be connected via wire (Ethernet, coaxial, or fiber-optics) or via wireless technology (radio waves, satellite technology, or cellular networks). To connect their systems, transit operators commonly use multiple networks simultaneously.
- **Cloud vendor services** (rectangle across the top in Figure 3-2): The specialized software of networked systems is physically hosted in servers or in special computer hardware. Although it is common for transit agencies to own these assets, they can also access and use these types of assets from third-party vendors of cloud services. Cloud services can range from providing access to software over the internet to entire data centers with a large selection of computing and data storage capabilities as well as networking assets. Being scalable, cloud computing services can be adjusted to meet the specific needs of the customer. Although buying cloud services from vendors reduces routine maintenance and renewal activities on the operator side, the agency is still responsible for ensuring the continued delivery of quality services to its customers and must continue to manage risk.

Figure 3-3

Typical Communication Network Options



3.4 Transit System Types for End-Use Operations

This section discusses the more common types of transit systems currently in use to support day to day operations and deliver the general end-use functions of the six systems asset classes. The following systems may use a networked system to deliver the primary system function or for control, monitoring, and data management purposes. As transit system technology advances, more and more systems are incorporating and relying on a networked component.

3.4.1 Vehicle Control and Signaling

Vehicle control and signaling systems monitor and control vehicle movements to ensure safe and efficient operation. In transit operations, this primarily refers to train control systems employed on light, heavy, and commuter rail services. Section 3.4.1.4 provides additional information on transit signal priority systems, which are used with buses and light rail in mixed-traffic environments through controlling traffic signals. Driverless or fully automated trains, which use emerging train control technologies, are not discussed here but may become more common in future transit operations.

Depending on the operational requirements, signal control systems may be simple, manual installations that communicate vehicle movement information from wayside signals to train operators via line of sight (for example, streetcars), or complex, automatic train control (ATC) systems with additional equipment onboard the vehicle (for example, heavy rail cars on an exclusive right-of-way). In addition to the wayside and vehicle-borne hardware and software equipment, ATC systems are supported by data and central control centers that communicate with the field equipment via a network.

Rail transit systems typically use ATC technologies that may be composed of the following key functions:

- **Automatic train protection (ATP)** maintains safe train operation through a combination of train detection, route interlocking, and speed regulation to prevent injuries to personnel and passengers, as well as damage to equipment.
- **Automatic train operation (ATO)** controls basic operating functions, such as vehicle motion, station stopping, and passenger information, within the operating limits of the ATP.
- **Automatic train supervision (ATS)** provides the link between the central control operator to the overall ATC system to enable general monitoring and management, sometimes with additional diagnostic, dispatching, route control, and scheduling functionalities.

In current rail transit applications, the three most common types of signal control systems in operation are the following: (1) fixed block (which can be either manual or automated), (2) communications-based train control (CBTC), and (3) positive train control (PTC). (Both CBTC and PTC systems use ATC technologies.) Fixed block and CBTC systems perform the same fundamental train protection function, and a rail line or service will use one or the other, not both simultaneously. However, an agency transitioning from the traditional fixed block system to a modern CBTC system may have both types of systems in operation on different parts of their rail system for a period. PTC is most commonly installed as an overlay to a basic train control system and is required on most commuter rail passenger routes per the Rail Safety Improvement Act of 2008 but does not impact heavy or light rail lines at this time. In general, the Federal Railroad Administration provides oversight of railroad train control and signaling systems, providing guidance and regulations.

3.4.1.1 Fixed Block Signal System

Traditionally, signaling systems have used discrete sections of track, or "blocks," to control the movement of trains, as depicted in Figure 3-5. Each block or section of track is determined by fixed wayside signals at the entrance and exit, hence "fixed block." The signals protect the block by preventing a second train from entering when another train is still occupying the block. The entrance signal indicates to the train operator whether to proceed.

Fixed block signal systems may contain elements that do more than just maintain train separation or protection. The system may employ ATO or ATS functions to improve safety and efficacy of operations. At a minimum, fixed block systems are composed of infrastructure components to provide the wayside signaling capability. These often include the visual signals themselves, track circuits, and switch machines, as well as support equipment dependent on the technologies employed. More complex systems may include equipment installed in the vehicles (for example, operator consoles, event recorders), as well as control or data center components for communications (for example, dispatching, servers, network). A sample of common fixed block signal system assets is included in Table 3-2.

Table 3-2

Sample Fixed Block Signal System Asset Base

Common Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
• Vehicle-borne equipment (e.g., receivers) • Wayside signals • Interlocking (e.g., switch machines) • Track circuits • Insulated joints • Impedance bonds • Relays and housings • Grade crossing system (e.g., gates, signals) • Train stops • Power supply and cables • Batteries	• SCADA* • ATC* • Monitoring systems*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access point **Data Centers** • Servers* • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

** These assets are often located at data centers.*

3.4.1.2 Communications-Based Train Control

With CBTC, or moving block systems, there is no dependency on traditional track-based train detection because the system instead uses automatic and continuous bidirectional digital communication between trains and wayside equipment (Figure 3-4). In a CBTC system, trains continuously communicate their status (for example, location, direction, speed) via radio to wayside processors, allowing the system to dynamically define the protected section or block for each train instead of statically fixing the blocks with infrastructure (unless the system uses virtual block technology, which operates similar to moving block technology, but still defines physical blocks). CBTC systems usually divide the railway into areas or regions, each with its own wayside computer control and radio transmission system.

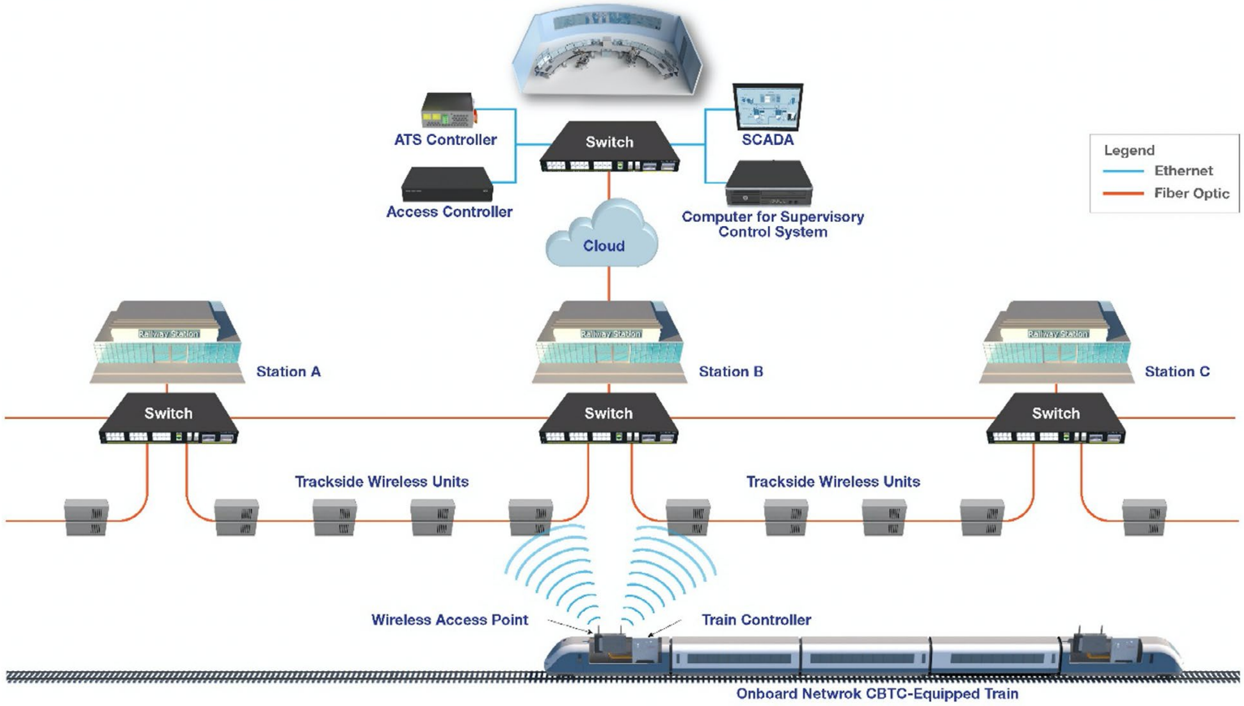


Figure 3-4 *Generic Communications-Based Train Control System Architecture*

Although the train-to-wayside communications of CBTC systems do not require track-based train detection elements, some CBTC applications use the communications as an overlay on less-precise track circuits. As such, many of the same components within CBTC mimic traditional train control systems. Similarly, CBTC systems may incorporate ATO or ATS functions in addition to the ATP foundation.

A CBTC system may share many of the same systems elements as a fixed block signal system listed in Table 3-2, but generally does not require traditional hardware such as control relays and bonds, track circuits, and insulated joints. Figure 3-5 juxtaposes the key operational differences between fixed block and CBTC (note how the headway distance is reduced to match the braking curve in a CBTC system).

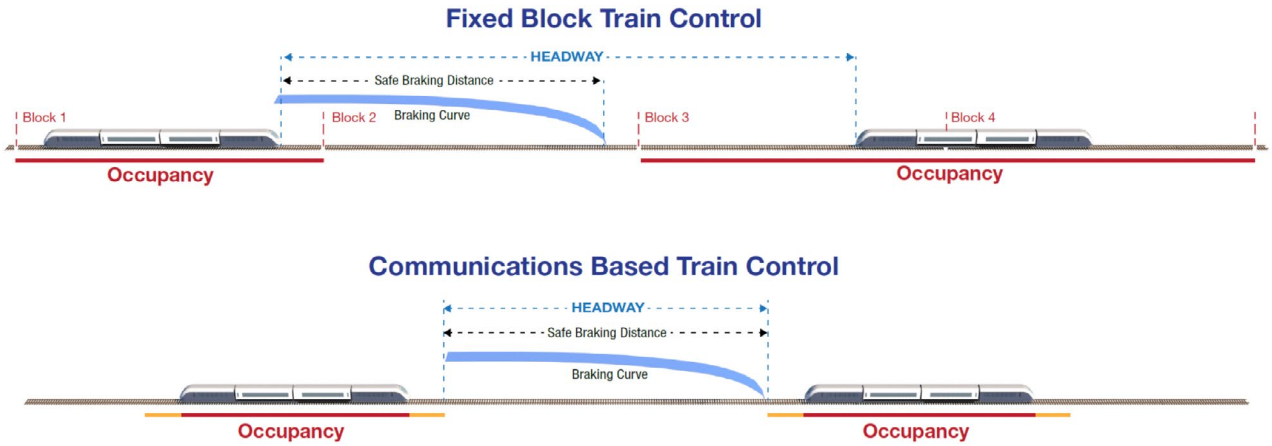


Figure 3-5 *Fixed Block Train Control and Communications-Based Train Control*

3.4.1.3 Positive Train Control

The Federal Railroad Administration (FRA) defines a PTC system as an integrated command, control, communications, and information system designed to prevent train accidents by controlling train movements with safety, security, precision, and efficiency. PTC systems improve railroad safety by significantly reducing the probability of collisions between trains, casualties to roadway workers and damage to their equipment, and over speed accidents.

PTC systems vary widely in complexity and sophistication based on the level of automation and functionality being implemented. System characteristics can include collision avoidance or train separation, speed regulation, temporary speed restrictions, and wayside worker safety.

There are two main PTC implementation methods being developed. The first uses fixed signaling infrastructure, such as coded track circuits and wireless transponders, to communicate with the vehicle onboard speed control unit. The other uses wireless data radios spread out along the line to transmit dynamic information. The wireless implementation also allows the train to transmit its location to the signaling system, which could enable the use of moving or virtual blocks (that is, CBTC).

Figure 3-6 presents an example of a basic system architecture for a generic PTC system. Equipment onboard the train and in-track transponders communicate train position, speed, and other information via a wireless communication (radio) network to the wayside signals and PTC back office. A GPS satellite is used to reference the train's position. The system receives the train information and implements speed restrictions, switch alignments, work zones, and other movement control as required via the network and wayside signals.

PTC subsystems and components depend on the specific installation, but typically include many of the assets listed in Table 3-3.

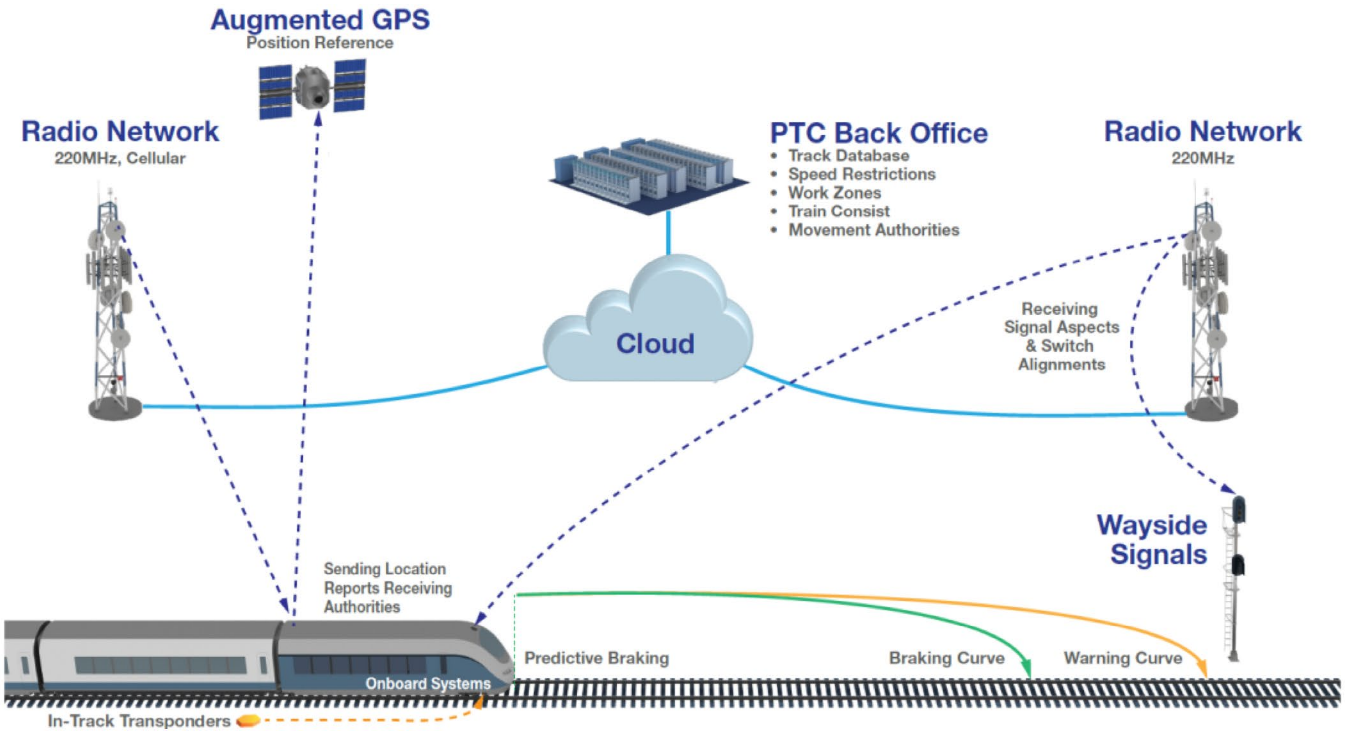


Figure 3-6 *Positive Train Control Basic System Generic Architecture Derived from Rouse (2019)*

Table 3-3

Sample PTC System Asset Base

Common Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
Vehicle-borne • Onboard computer and displays • Event recorders • Radios • GPS • Antennas • Transponder readers **Infrastructure** • Wayside interface units • Transponders • Switch-monitoring systems • Radio and cellular towers • GPS antennas • Cabling	• PTC software*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access points **Data Centers** • Servers* • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

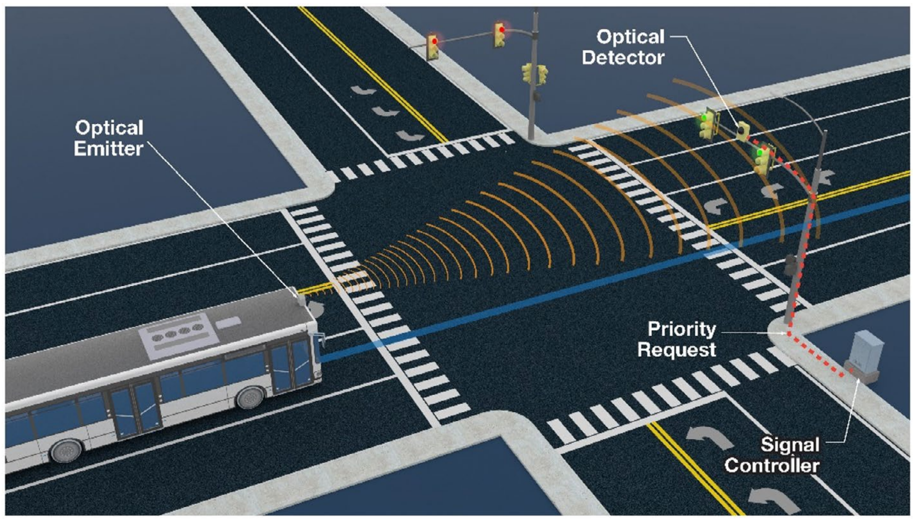
** These assets are often located at data centers.*

3.4.1.4 Transit Signal Priority

Transit signal priority (TSP) is a name for various operational techniques that aim to improve service and reduce delay for mass transit vehicles at intersections controlled by traffic signals. TSP applies to buses and light rail or streetcar service in mixed traffic areas. Whereas TSP serves a different purpose than the train control systems discussed above in Section 3.4.1, it is an operational system with hardware and software (common assets listed in Table 3-4) that interact with or control signals (in this case traffic signals) governing the movement of transit vehicles.

Figure 3-7

Transit Signal Priority System



The two most common TSP strategies are a decrease in red signal time and an increase in green signal time for transit vehicles to reduce the time spent passing through intersections and corridors. TSP systems can range from very simple to very complex applications, such as those that integrate Intelligent Transportation System technologies and span jurisdictions.

TSP systems often involve the interaction of four major subsystems: the transit vehicle, transit fleet management, traffic control, and traffic control management. These four subsystems are linked with the following four functional applications:

- A **detection system** that captures the location, time, and approach of the vehicle requesting priority
- A **priority request generator** that receives the detection system information and alerts the traffic control system that the vehicle would like to receive priority (It also manages multiple concurrent requests as necessary.)

- **Traffic control system software** that processes the request and decides whether and how to grant priority based on the programmed priority control strategies and functional requirements of the traffic jurisdiction
- **Overall TSP system software** that manages operations and settings, collects data, and generates reports

Table 3-4

Sample Transit Signal Priority System Asset Base

Common Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
Vehicle-borne • Transponder readers • GPS • GPS antenna/locator **Infrastructure** • Traffic signal controllers at signalized intersections • Vehicle detection system equipment (e.g., optical, loop-based, GPS-based, radio-frequency-based)	• Signal controller software (typically from controller manufacturer)* • Specialized TSP software*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access points **Data Centers** • Servers* • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

** These assets are often located at data centers.*

3.4.2 Traction Power/Electrification

Transit agencies operating electric rail vehicles or trolley buses use a traction power system that transmits high-voltage power generated remotely to electrify the transit vehicle's propulsion system and electronic devices. The system voltage and type of power distributed (alternating current [AC] or direct current [DC]) depend on the vehicle type and mode. The three main parts of a traction power system are the following:

- Power supplies (typically from utility companies, but some agencies may have the ability to generate their own from a power or combined heat and power plant)
- Substations where the supplied power is made suitable (transformed) for train operations
- Power distribution and contact system (ground-level third rail or overhead contact system [OCS])

The distributed power is drawn from the contact system by collection equipment installed on the vehicles (for example, shoes, pantographs, and trolley poles). Collection equipment assets are typically associated with the vehicle from a management perspective as opposed to being considered part of the traction power system. Transit agencies may also use central control hardware and software elements to monitor and manage the overall traction power system, as with other networked systems.

Some agencies use the traction power system to supply electricity to non-vehicle assets, such as stations, lighting along the right-of-way, or infrastructure related to other transit systems, such as train control and signaling. Other agencies use completely separate electrification systems to supply power to non-traction power applications. Others rely entirely on local electrical utilities to electrify their non-vehicle service assets.

Non-traction power electrification often has different power requirements (for example, AC vs. DC or varying voltages) from that of traction power electrification and may use additional infrastructure or separate equipment. For asset management purposes, all electrification system assets, whether for traction power or other applications, can be treated similarly.

3.4.2.1 Power Substations

A traction power substation (TPSS) (or unit substation as often referred to for non-traction power electrification) is composed of the switchgear, transformers, rectifiers, and protection and control equipment (for example, SCADA) that receive source power, convert the power to meet the voltage, current, and frequency requirements of the rail or bus transit line, and supply the transformed power to the distribution system. Substation equipment differs depending on the type and purpose of the power supply.

Substations are spaced along the service corridor as needed to meet load demand and voltage-drop requirements. They are permanent structures that can take the form of a room within or adjacent to another facility, such as an underground rail station, or a standalone building close to the service route. TPSSs often have a housing for control equipment (as depicted in Figure 3-8) with an adjacent fenced, open-air enclosure for the transformer(s) (depicted in Figure 3-9).

Figure 3-8 *DC Traction Power Substation—Rectifier and Switchgear Equipment Inside Substation Housing*

Figure 3-9 *DC Traction Power Substation—Rectifier Transformers in Open-Air Enclosure*

Table 3-5 presents a sample of common TPSS assets. See Appendix D for a more detailed breakdown of typical assets based on the type of TPSS (AC supply, AC booster, AC tie-breaker, and DC).

Table 3-5 *Sample Traction Power (or Unit) Substation Asset Base*

Primary Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Communication Network Assets
• SCADA node equipment • Communications node equipment • Ground and test devices • Control panels • Ground and return buses • Utility and distribution disconnect switches • Circuit breakers • Lightning arresters • Step down and traction transformers • AC distribution switchgear • Control power and backup power (battery charger, battery bank, control panel) • Facility air filtration and drainage systems **Unique to DC TPSS** • Rectifier transformer • Traction rectifier • DC distribution switchgear	• SCADA software*	**Office or Substation** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access points **Data Centers** • SCADA servers* • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

**These assets are often located at data centers.*

3.4.2.2 Traction Power Distribution Systems

Distribution systems carry the converted power from the substations to the service vehicles and are typically composed of the following three parts:

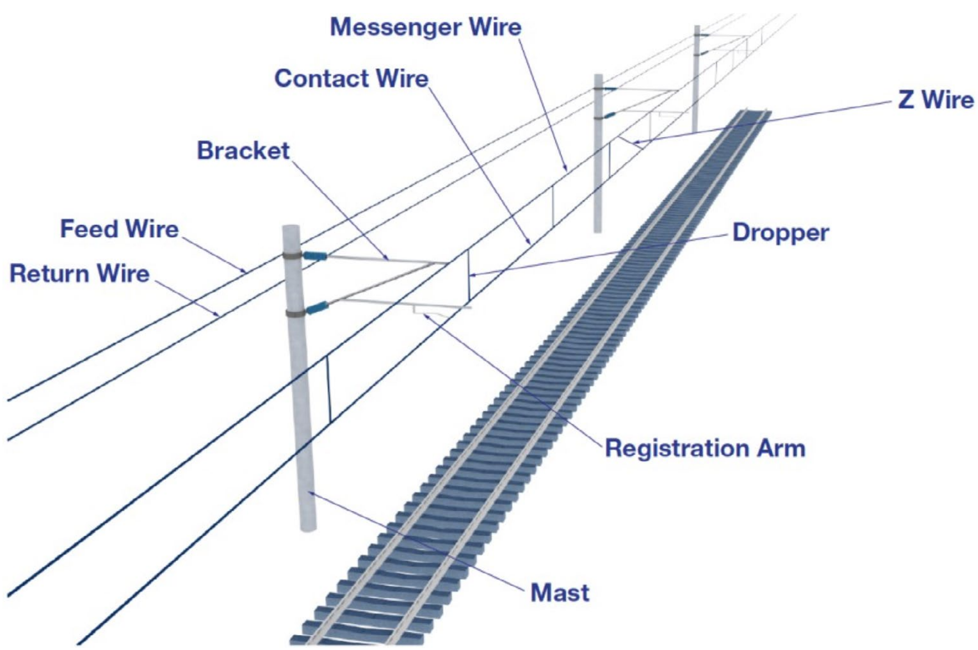
- Feeder cables that carry power from the substation to the contact system/ conductors
- Negative return cables that connect the rails or return conductor back to the substation (typically the running rails)
- Contact system with conductors (third rail or OCS) from which the vehicles draw power

Overhead Contact System

OCS transmit power by way of a continuous, energized, uninsulated contact wire (that is, conductor) suspended above the track or roadway (Figure 3-10). Transit vehicles that draw power from an OCS have a pantograph (rail only) or trolley poles that press against the underside of the contact wire to collect current. OCS used in rail and bus transit can be a single wire (for low-speed and power vehicles with pantographs or trolley poles) or a catenary system (pantograph only). Catenary refers to a multi-wire system with at least a contact wire, as well as a messenger wire that helps to support the contact wire between poles and provides more electrical conductivity. OCS wire tensions vary. Less commonly, OCS may have a rigid wire installation that acts more like an overhead conductor rail.

Figure 3-10

Overhead Contact System Key Components



OCS are typically composed of conductors, anchorages to create and maintain tension along the conductors, and a support or suspension system. OCS equipment is similar for both DC- and AC-powered systems and may include the following assets:

- Contact and messenger wire
- DC connect switches or breaker houses
- Sectionalization equipment (breaks and switches)
- Stray current equipment
- Power and return cables
- Surge arrestors
- Suspension system (poles, cantilevers, cross-spans, wall or soffit attachments)
- Cable trays, conduits, duct banks
- Support arms, connectors, tensioners, and insulators

Third-Rail Contact Systems

A third-rail contact system is another form of transmitting power to rail transit vehicles that uses a continuous conductor rail installed on insulators to the side of and parallel to the track. Third-rail systems are most commonly used on grade-separated, dedicated guideways like those in subway systems.

Trains electrified by a third rail draw power through metal contact blocks or “shoes” installed on the vehicle that contact the conductor rail. The negative return is through one or both of the running rails. Most third-rail systems supply DC electricity. Following are common elements of a third rail contact system:

- Contact (bi-metal, third) rail
- Bracketry, insulators, coverboard
- DC connect switches or breaker houses
- Stray current equipment
- Power feed and return cables
- Cable trays, conduits, duct banks, maintenance holes

3.4.3 Communications and Control

Communications and control systems support transit agencies with functions for critical operations, such as passenger and staff communications, transit vehicle control, security, and system control and monitoring. Communications systems components are not confined to the boundaries of a single facility or right-of-way section but are often distributed over large segments or the entirety of the transit agency's service area. Because the subsystems and system elements are physically disseminated throughout the agency's service area, a network is required to link all parts for the communication system to operate as designed.

Figure 3-11

Communications Tower

As discussed in Section 3.3, networked systems require (1) networks to connect all system elements and allow the unified, cohesive, and synchronized operation of the system and (2) control, monitoring, and data storage capabilities. Networks can be wired (using cables) or wireless. Wireless communications networks are particularly instrumental in allowing transit vehicles to be fully integrated into a wide array of systems. Common wireless communications include broadcast radio, microwave, Wi-Fi, mobile (cellular), Bluetooth, infrared, and satellite.

To link the entire array of communications and control systems, transit operators commonly combine cable and wireless network options available.

Cloud Services: The specialized software needed to perform specific communications and control functions is physically hosted in servers or in special computer hardware. Although it is common for transit agencies to own these assets, they can also access and use these types of assets from third-party vendors of cloud services. Cloud services can range from accessing software on the internet to using servers, storage, databases, and networking assets. Although buying cloud services from vendors reduces routine maintenance and renewal activities on the operator side, the agency is still responsible for ensuring the continued delivery of quality services to its customers. In other words, although services can be purchased the agency continues to be responsible for managing risk.

Table 3-6 provides an overview of the asset base of the five communications and control systems discussed in this section.

Table 3-6 *High-Level Sample of Transit Communications and Control Systems Asset Bases*

System	Primary Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
CCTV	• Cameras • Digital video recorders • Video management servers[a] • Video control servers[a] • Video analytics servers[a]	• Camera streaming and recording licenses[a] • Client viewing licenses[a] • Video analytic client licenses[a] • Video analytic camera licenses[a]	**Office** • PCs, laptops, tablets • Monitors • Switches and Routers • Firewall devices • Access points **Data Centers** • Servers[a] • UPS equipment[a] • Battery backup[a]	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication
PA	• Public address head-end hardware[a] • Public address microphone consoles • Speakers and amplifiers	• Public address head-end software[a]		
Radio	• Transmitter site equipment • Receiver site equipment • Simulcast site equipment • Radio head-end equipment[a] • Antennas (including DAS)[b] • Radio consoles • Radios (several types)	• Radio head-end software[a]		
Telephone	• Telephone PBX (including ESS[c] PBX[d]) • Telephony application servers[a] • Telephones (all types)	• Telephony applications (e.g., voicemail, voice recorder, call accounting, conferencing)[a]		
SCADA	• SCADA servers[a] • RTUs[e] • PLC[f]	• SCADA software[a]		

[a] *These assets are often located at data centers.*

[b] *DAS (distributed antenna system) is a system of managed hubs and remote antennas that distributes a wireless signal to a series of connected indoor or outdoor multiband, multitechnology radio heads. At the head-end of the DAS, service providers typically locate base stations to provide the cellular signal. A main hub takes that signal, digitizes it, and distributes it to other hubs and radio heads via a high-bandwidth fiber-optic network. At the antenna, the radio converts the signals from digital to RF and RF to digital (LeFevre, 2014).*

[c] *ESS (electronic switching system) is a telephone switch that uses digital electronics and computerized control to interconnect telephone circuits for the purpose of establishing telephone calls.*

[d] *PBX (private branch exchange) is a private telephone network used within a company or organization. The users of the PBX phone system can communicate internally (within their company) and externally (with the outside world), using different communication channels like Voice over Internet Protocol (VoIP), Integrated Services Digital Network (ISDN), or analog.*

[e] *The RTU (remote terminal unit) is a device installed at a remote location that collects data, codes the data into a format that is transmittable and transmits the data back to a control center. An RTU also collects information from the master device and implements processes that are directed by the master. RTUs are equipped with input channels for sensing or metering, output channels for control, indication or alarms and a communications port.*

[f] *A PLC (programmable logic controller) is an industrial solid-state computer that monitors inputs and outputs, and makes logic-based decisions for automated processes or machines. Machine Design.*

3.4.3.1 Closed Circuit Television System

CCTV systems provide transit agencies with the ability to surveil and monitor various elements and areas of the service network. These systems typically use dispersed video and sometimes audio-recording equipment that transmit or log recorded data over a network to be observed from a central control location(s) in real time or accessed in review. Recording devices are often located inside the passenger area and on the exterior of transit vehicles, inside and around internal agency properties (for example, administrative offices, maintenance facilities, tunnels), and within areas accessed by passengers (for example, stations, stops, parking garages).

Transit agencies deploy CCTV systems for many reasons, including public and staff safety. CCTV systems can also assist with operations management, vehicle incident investigations, emergency response, revenue loss prevention, and passenger-flow management. More advanced systems can also assist with the detection and tracking of suspicious objects, persons, or chemical substances.

Common assets that compose CCTV systems are listed in Table 3-7.

Table 3-7 *Sample Closed Circuit Television System Asset Base*

Primary Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
• Cameras • Digital video and audio recorders • Video management servers* • Video control servers* • Video analytics servers*	• Camera streaming and recording licenses* • Client viewing licenses* • Video analytic client licenses* • Video analytic camera licenses*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access points **Data Centers** • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

These assets are often located at data centers.

3.4.3.2 Public Address and Digital Display Systems

PA and digital display systems provide audio and visual information to passengers inside vehicles, on platforms, or at other locations in and around transit stops and stations. These systems provide a safety-critical capability that allows members of the agency's transit operations to communicate with passengers in the event of an emergency. In addition, PA and digital display systems can support wayfinding and communication of real-time operational information, such as service alerts or delays, arrival times, and on-route stops and destinations using announcements and variable message signs (VMS).

Although PA or digital display systems can be standalone installations, they are often integrated to enable coordinated communication of service information to passengers, including those who are visually or aurally impaired.

The basic functionality of a PA system involves taking an input from a microphone or recording and sending it through head-end electronics (for example, digital signal processors, power amplifiers) to disseminate via speakers. Visual displays function with a similar stream, where text or graphical data is determined by central software and sent over a network to the local display screens. Specific equipment for PA systems may include the assets listed in Table 3-8.

Table 3-8 *Sample Public Address and Digital Display Systems Asset Base*

Primary Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
• Public address head-end hardware* • Public address microphone consoles • Speakers and amplifiers • Dynamic message signs • Line-of-sight display • Digital advertising signs • iSigns	• Public address head-end software*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access and control points **Data Centers** • Servers* • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

**These assets are often located at data centers.*

3.4.3.3 Radio and Telephone Communication Systems

Radio and telephone communication systems provide means for voice and digital communications to fulfill many functions within transit agency operations. Telephone and radio systems are typically standalone but can be integrated with other communication systems.

Radio systems allow wireless communication between agency operations, maintenance, and security staff. For example, radio systems enable vehicle operators and central control or dispatch to transmit vehicle orders or instructions during incidents. They also enable communication channels with municipal emergency response teams. Key radio system assets are listed in Table 3-9.

Table 3-9 *Sample Radio System Asset Base*

Primary Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
• Transmitter site equipment • Receiver site equipment • Simulcast site equipment • Radio head-end equipment* • Antennas (including DAS) • Radio consoles • Radios (portable, hand-held, etc.) • Base station • Transmission towers • Amplifiers • Communication rooms	• Radio head-end software*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access points **Data Centers** • Servers* • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

**These assets are often located at data centers.*

Telephone systems are wired communications often seen in back-end administrative and support applications for agency personnel, as well as emergency call-box networks that connect to transit or local police departments for passenger use. Common types of telephone system assets are included in Table 3-10.

Table 3-10 *Sample Telephone System Asset Base*

Primary Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
• Telephone PBX • Telephony modems • Telephones (all types)	• Telephony applications (e.g., voicemail, voice recorder, call accounting, conferencing)*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access points **Data Centers** • Telephony application servers* • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

3.4.3.4 Computer Aided Dispatch and Automatic Vehicle Location Systems

CAD/AVL systems are a critical element of intelligent transportation systems, particularly for transit bus operations. On a basic level, CAD refers to the hardware and software equipment that enables agency dispatchers to communicate with bus operators and see the real-time location of each bus through the AVL system using global positioning system (GPS) satellites to provide location data.

CAD/AVL systems connect bus vehicles to central agency dispatching (for example, scheduling and messaging) software, transit signal priority systems, as well as on-board and wayside visual and annunciation systems that provide passengers with route information. Some CAD/AVL systems include functionalities to log detailed vehicle data, send digital voice and text messages, manage detours, navigate new or changed routes, record pre- and post-trip vehicle inspections, coordinate transfers (inter- or intramode), and facilitate faster responses to field service calls. Data from a CAD/AVL system can be used to analyze transit operations, such as service performance and scheduling, vehicle collisions or near misses, and ridership levels. Location data can also support trip planning or tracking software or apps to assist passengers.

CAD/AVL systems often involve two major subsystems: the transit vehicle and the central control center or dispatch. On board the vehicle, typical hardware assets include a GPS transmitter/receiver and a vehicle control module (that is, operator display for visual information and digital communications) with associated software. The central control center will have manufacturer-created specialized CAD software installed on one or several computers for dispatchers to access. The two subsystems communicate over a radio or cellular backbone with information logged on a data server.

3.4.3.5 Supervisory Control and Data Acquisition Systems

SCADA systems are used to monitor, control, and manage transit service and related infrastructure and equipment by creating an interface between distributed hardware and a core communications network. These systems can collect operational status data, display or process this data according to established protocols, and transmit control commands to equipment. Wireless or virtual private networks can also create additional remote diagnostic, fault detection, and maintenance functionalities.

Many transit agencies use an integrated SCADA technology to manage other vehicle-related systems such as traction power, signaling, CAD/AVL, revenue collection, and tunnel ventilation. As such, SCADA systems may share cabling and conduits with these other systems. A typical SCADA system comprises input/output signal hardware, controllers, software, and network and may include other assets listed in Table 3-11.

Table 3-11

Sample SCADA System Asset Base

Primary Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
• RTUs • PLC • SCADA servers*	• SCADA software*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access points **Data Centers** • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

**These assets are often located at data centers.*

3.4.4 Revenue Collection

Modern transit fare revenue collection systems are typically described in terms of (1) customer-facing devices such as ticket vending machines, card readers, and fareboxes; (2) websites and mobile applications (apps) for account management as well as fare sales, payment, and enforcement; and (3) back office transaction processing, system configuration, and reporting.

Fareboxes and faregates are very common types of transit fare collection assets in the United States that are linked to a back-office system that supports data collection and reporting. Fareboxes are designed to be installed onboard the transit vehicle (buses and sometimes trains), and faregates are installed to regulate access into transit stations. They most often support transit fares paid with cash or electronic fare media. Electronic fare collection supports the processing of fare media with a magnetic strip, barcode, and/or a radio-frequency identification chip, such as smart cards or fare tickets. Next generation revenue collection systems may incorporate fare validators, or smaller electronic readers, to accept payment on vehicles or in stations.

Open payment systems, such as mobile ticketing applications, represent a rapidly growing fare collection technology. Applications can be downloaded by a customer and used to perform fare payment avoiding the need to process cash or have passengers visit a ticket machine or ticket office.

Figure 3-12

Customer-Facing Fare Collection Assets at a Transportation Hub

Table 3-12

Key Fare Collection Assets and Back Office Hardware and Software Functions

Primary Function Assets	Back Office Hardware and Software Functions
Farebox	
• Farebox and all associated wiring and mounting hardware • Driver display unit (included as part of the farebox or as a separate integrated device) • Vaulting system • Spare modules/devices	Support data collection and reporting
Electronic Fare Collection	
• Card/ticket readers/validators and wiring/mounts • Driver display units and wiring/mounts • Mobile access routers and wiring/mounts • Vending machines and wiring/mounts • Fare gates and wiring/mounts • Customer service workstation and all peripherals • Test facility including hardware and software • Retail sales unit devices • Fare inspection devices • Customer mobile app • Agency mobile app(s) • Fare gate interface • Emergency release mechanisms	Support many system functions including transaction processing and reporting
Data Reconciliation	
• Parking validation/enforcement equipment • Equipment to support interface with merchant acquirer, banking gateway for processing credit/debit card transactions • Equipment to support interface with regional fare collection system	Data reconciliation with banking and regional fare collection systems
Mobile Ticketing Apps	
• Customer mobile apps • Barcode readers	Application configuration, transaction processing, and reporting

3.4.5 Information Technology (Business Applications)

To function, a computer system relies on three basic groups of system elements: hardware (for example, workstations, servers, switches, and routers), a network (for example, coaxial or fiber-optic cabling, wireless equipment, radio antennas, receivers, and transmitters), and software (that is, business applications). Information technology systems in this handbook refer to business applications, or the computer programs or software capable of performing a set of specialized business functions. Business applications range from a simple word processing system to complex enterprise resource planning schemes that can combine several business applications and processes under a single platform. Combining functions can capitalize on a wider network of information resources and enhance computing capabilities.

Business applications support transit operators on key administrative and operational functions that include the following:

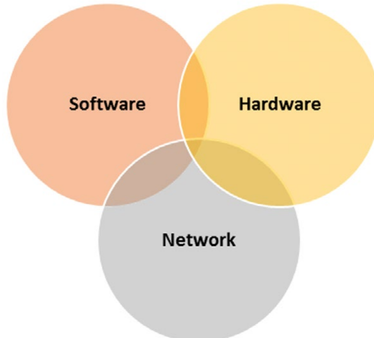
- Accounting, budgeting, and financial management
- Capital programming
- Asset management (for example, enterprise asset management system (EAM) or maintenance management system (MMS))
- Human resources and payroll
- Materials management and procurement
- Transit operations
- Equipment maintenance
- Crew management and scheduling
- Program management

3.4.5.1 Key System Elements: Software, Hardware, and Network

Information technology systems usually encompasses three main groups of system elements: software, hardware, and network. To be fully operational, a business application (software) requires full integration with corresponding hardware elements and a network. The absence of any group of system elements displayed in Figure 3-13 will prevent the business application from performing its required function(s).

Figure 3-13

System Element Groups Needed to Run a Business Application



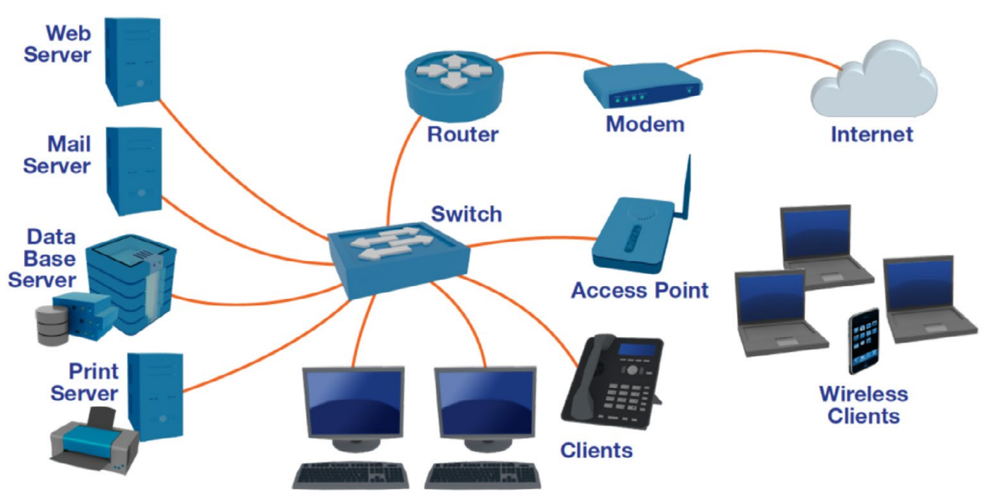
Software: Encompasses the business applications written to provide functions set to specifications. Business applications are physically hosted in servers or PCs. Operators might opt for using web applications that reside on a server and can be accessed via an internet browser.

Hardware: Encompasses physical assets such as personal computers, wireless devices (for example, laptops, tablets, and clocks), monitors, servers, switches, routers, modems, access points, firewall devices, and printers. The interaction of system operators with hardware fosters a human-machine interface (HMI) that allows them control and monitor the performance of their systems.

Network: The "lifeline" that connects or links all subsystems and individual system elements and the medium through which commands and data/information travel. The network is the medium that connects machine-to-machine (M2M). The network sends and receives data via cables (for example, coaxial, Ethernet, and fiber-optics) and/or wireless via radio waves (for example, Wi-Fi, microwaves, cellular, and satellite connections). The system can also connect its system elements to the cloud via the internet, which is linked via cable and/or wireless channels. An internet connection known as Internet of Things (IoT) allows systems exchange data among designated system elements.

Figure 3-14

Selected Information Technology Hardware Elements



Adapted from Retana (2016)

Table 3-13

Summary of System Elements, Functions, and Individual Assets

System Element Group	Software	Hardware	Network
Function	Control the business rules established to perform required functions	Computing, data storage, connection to the network, cybersecurity, etc.	Transfer of information/data
Sample of system elements or assets	Specialized computer program(s)	**Office assets:** PCs, laptops, monitors, switches, routers, modems, printers, access points, firewall devices, etc. **Data center:** servers and supporting accessories such as racks, and cabling. Support systems include access control, ventilation and cooling, fire suppression, connections to external networks, etc.	**Cable:** coaxial, Ethernet and fiber-optics **Wireless:** wireless devices, antennas

3.4.5.2 Business Application Access Options

To meet its specific business requirements, a transit agency has several avenues to access business applications. The development and procurement of these business applications range from fully customized applications built entirely by in-house personnel to those that are purchased or obtained under a subscription arrangement. Having in-house IT personnel capable of developing and implementing an agency's own business applications allows for easier customization of applications to match changes in business requirements over time.

Commercial options can be obtained off-the-shelf with the price dependent on the number of user licenses. This type of arrangement commonly provides a limited amount of time for use after which there is an expectation of additional investment for subsequent upgrades. Costs associated with the procurement and implementation of business applications will increase as the level of customization increases.

Transit operators might opt for using software and hardware and networks from a cloud computing provider. In this type of arrangement, users link their hardware (for example, workstations, hand-held devices, tablets) to the cloud, where the computing and storage functions are performed. Cloud services can be quite comprehensive and include access to software, data centers and networks. Being scalable, a cloud computing service can be adjusted to meet the specific needs of the customer. Although this type of arrangement may contribute to reduce or ultimately eliminate the transit operator responsibilities to operate and maintain its own networks and/or data centers, the agency is still fully responsible for the delivery of quality services to its customers. In other words, although services can be purchased the agency continues to be responsible for the ensuring the optimal operation of the system while balancing risk, cost, and performance.

3.4.6 Tunnel Support

To support the provision of safe and reliable service along the right-of-way, transit properties rely on utility systems such as tunnel ventilation and exhaust. These systems are similar to those that provide support functions to fixed structures like stations and facilities but can extend over long distances along the right-of-way. The operation of these critical support systems must rely on adequate network linkage of their subsystems and system elements. The network connects the control, monitoring, and data storage assets (for example, servers, workstation, and digital display units) with the primary function assets (for example, fan plants in the case of a tunnel ventilation system). An important consideration for systems that extend over long distances is whether the power supply is drawn at various locations from a public utility company or whether the transit agency uses its own power distribution system to support its operation.

Figure 3-15

Subway Tunnel

3.4.6.1 Tunnel Ventilation and Exhaust System

Transit agencies operating rail vehicles (and sometimes buses) will typically use some form of tunnel ventilation and exhaust equipment for underground operations similar to assets included in Table 3-14. This equipment is usually controlled by a SCADA system and is commonly integrated with a fire management system. Although vent shafts and permanent enclosures might be maintained by building maintenance personnel, they are integral elements of the tunnel ventilation system.

Table 3-14

Sample Tunnel Ventilation and Exhaust System Asset Base

Primary Function Assets	Software Assets	Control, Monitoring, and Data Storage Assets	Network Assets
• RTUs • PLC • Fan assemblies and individual fan motors • Boosters • Tunnel ducts and shafts • Damper assemblies • Sensors/ thermostats (e.g., air flow monitors, air quality monitors) • SCADA servers*	• SCADA or specialized ventilation and fire management software*	**Office Assets** • PCs, laptops, tablets • Monitors • Switches and routers • Firewall devices • Access and control point **Data Centers** • UPS equipment* • Battery backup*	**Cabling Options** • Ethernet • Coaxial (copper) • Fiber-optics **Wireless Options** • Broadcast radio • Microwave Communication • Wi-Fi • Mobile communication systems (cellular) • Bluetooth technology • Infrared communication • Satellite communication

**These assets are often located at data centers.*

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Section 4

Systems Asset Inventories and Hierarchies

4 Systems Asset Inventories and Hierarchies

This section provides guidance on developing asset inventories and hierarchies for the different types of transit systems, including inventory best practices, key asset attributes to be considered as part of an agency's systems inventory, and example hierarchies as starting points for transit agencies to determine how best to organize their systems' assets.

As detailed in the *Transit Asset Management Guide* (FTA, 2016a), the asset inventory identifies all critical assets for which an agency has capital responsibility, the assets' locations, and important attributes such as age, expected useful life, cost, and class. How these assets are organized and what additional information is recorded about them is determined by an agency's organization, operations, and asset management policy, goals, and requirements.

A systems asset inventory uses hierarchies to organize the system's assets according to parent-child relationships. Like system structures, hierarchies are top-down decompositions that define the parent-child relationships of the physical systems assets and their parts. Systems hierarchies can go beyond a simple structure of physical (and virtual) systems assets to incorporate asset location, function, class, identification number, or other attributes. Hierarchies must align with the system structure, boundaries, and overall architecture (see Sections 2.2 through 2.4). Asset hierarchies go down to the lowest maintainable unit, as it is the maintainable unit to which the life cycle management procedures (inspection, preventive maintenance, rehabilitation) are applied.

Many elements of the transit systems discussed in Section 3 (for example, cameras, speakers, individual servers, workstations, switches, routers) may represent a very large number of equipment assets. Lumping similar types of assets together can help streamline the asset inventory for asset management and high-level capital planning purposes. However, for maintenance and performance monitoring purposes the agency may be better served tracking assets at a higher level of detail. For example, a single CCTV camera has a relatively small cost, but an agency managing thousands of cameras is making investments into the millions of dollars. It's important that critical, high value system elements, whether individual assets or groupings of assets, are included in the agency's asset inventory for improved life cycle and cost management.

4.1 General Asset Inventory Considerations

An asset inventory can be a simple spreadsheet or a complex database within or linked to an enterprise asset management software system. Regardless of the specific medium or format, having one central, unified asset inventory across an organization creates the best foundation from which an agency can manage its assets. An integrated approach creates an object-oriented data environment that enables a seamless connection between the asset, its distinguishing information, and any associated documentation.

This especially holds true for systems assets. Transit systems can span multiple operational disciplines or users and serve several purposes, making it critical that systems assets are tracked in a central location to avoid duplication or being overlooked. For example, some rail operators include their supervisory control and data acquisition (SCADA) systems as a subsystem of their traction power system; others have their SCADA system as a stand-alone system. Systems assets also can be touched by many different departments in the agency throughout their life cycles. For example, surveillance cameras installed on a bus may be procured by an engineering group as part of the overall bus fleet procurement, maintained by a communications group, and operated by security personnel.

It is also true that not all systems' assets are discrete units, or "widgets." Some are continuous, linear assets, such as fiber-optic cabling or overhead electrical contact wire. To effectively inventory these assets, percentages rather than quantities may better capture groupings of the assets by attribute (similar to what is currently done for FTA NTD AIM reporting on traction power OCS). Additionally, using an identification method based on geographic location or distance (for example, LiDAR) to inventory linear assets may allow for greater control in assigning, tracking, and analyzing asset information.

Asset identification and labeling is another critical tool for managing and tracking individual assets. Each asset should have a unique identifier that may use a coding method to specify attributes such as asset type, function, location, and manufacturer. For some asset types, physical, coded labels on assets or equipment improve identification.

4.2 Key Systems Asset Information for Inventorying

According to the Institute of Asset Management (IAM), asset information is a "combination of data about physical assets used to inform decisions about how they are managed, both for short-term operational purposes and for long-term strategic planning" (IAM, 2015b). The data collected and inventoried for systems assets can be designed to meet the needs of key stakeholders such as operations, maintenance, engineering, accounting, budget, and capital planning groups.

At a minimum, transit agencies should document the expected service years when new, the current age, the percentage of capital responsibility, and any entities sharing that capital responsibility for each systems asset. Including these attributes in the inventory will satisfy FTA NTD AIM reporting requirements, but more information may be needed to support an agency's specific asset management program and maturity level goals.

The age of an asset is often used as a basic indicator of its health or condition. In the absence of more detailed information, using an asset's age can be an acceptable method to predict investment needs. However, industry experiences have demonstrated that age is not always a reliable indicator of condition, as it is possible to see some new equipment fail more often than historical, existing equipment. The following are examples of attributes for which data could be collected to better and more efficiently predict and prioritize investments in systems assets:

- General attributes
- Year purchased, first in service, or manufactured
- Physical location (for example, address, geographic coordinates, vehicle type and number)
- Manufacturing model (allows for manufacture specific maintenance or defect campaigns in systems where multiple models are in use simultaneously)
- Available spares and parts
- Engineering documentation (for example, as-built drawings, as-maintained configurations, cut sheets, maintenance manuals, test results)
- Operational and performance attributes
- Duty cycle/utilization (expected and current status)
- Condition rating (or other performance measure, such as functional testing status) and date of last assessment
- Failures or defects
- Inspection dates and status
- Other maintenance history information
- Other system-specific diagnostic information
- Code compliance status
- Investment attributes
- Estimated life cycle costs/total cost of ownership
- Most recent capital investment date and scope

- Criticality to providing service (or other measure of redundancy or risk)
- Climate or extreme weather resiliency

Creating a dictionary of asset data terminology is strongly recommended to clearly define and standardize the terms used for asset classification and required attributes. Having a regularly updated and widely distributed document ensures that all stakeholders supporting a system life cycle understand the meaning and purpose of each piece of system asset data.

4.3 Software Asset Inventory

To support the operation of many modern systems, transit operators must dedicate substantial amounts of money to pay for software licensing. Depending on the size and complexity of an agency operation, spending on software licensing can range from a few thousand to millions of dollars annually. To assist them with managing their information systems, transit operators might want to have an inventory of all agency owned and licensed software/business applications. From the global perspective, the asset manager might want to establish the agency's effective license position[3] which could provide detailed information such as the number of times software has been installed. The following are software attributes commonly used for this type of inventory:

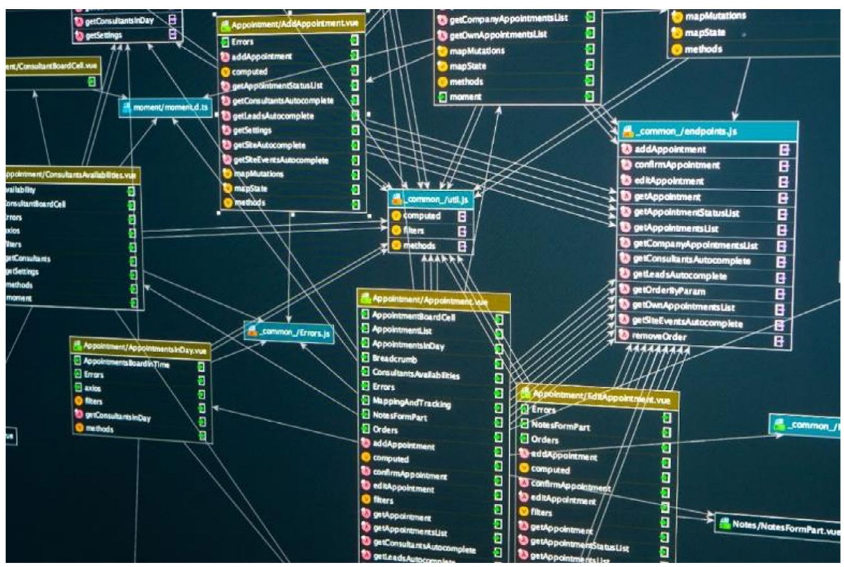
- Type of application:
  - Custom/in-house
  - Software as a service
  - Commercial, off-the-shelf
  - Hybrid (combination of application types)
- Lifecycle stage:
  - In development
  - In service
  - Retirement in progress
  - Retired from inventory
- In-service date (date in production)
- Retirement date
- Is this application considered a subsystem of another application?
  - If yes, what application is this a subsystem of?
- Core or critical
- Business criticality

[3] Effective license position means taking full inventory of software assets and comparing them against license documentation and installations. Vector Networks.

  - Business essential (essential to running everyday business)
  - Historical (needed for historical purposes)
  - Mission critical (critical to the agency mission)
  - User productivity (helps the user complete their tasks)
- Has business owner? (agency business owner responsible for funding and governing changes)
- Has resources available?
- Is an unsupported version?
- Is updatable?
- Has other risks?
- Estimated user count (numeric)
- Used by agency only?
- Used by the public?
- Does it have mobile capabilities?

Figure 4-1

Data Integration



4.4 Developing Systems Asset Hierarchies

Each transit agency should establish its own systems asset hierarchies to organize all asset classes and facilitate better management of business processes. The system architecture (Section 2.4) can serve as a starting point for understanding what the system elements are that must be included in the hierarchy and how they relate. Assets can then be placed into hierarchies based on (or sorted by) asset function (what it is designed to perform), class (type), steward (who is responsible), location, or a combination of comparable asset attributes or management characteristics. Other factors that might need to be considered when establishing asset hierarchies include maintenance and contractual protocols, as well as reporting requirements. For easier reporting, agencies can also consider aligning their hierarchies with NTD AIM requirements.

When developing systems asset hierarchies, agencies should consider engaging key stakeholders within the organization who will need to support the effort of entering and updating data, as well as operators and maintainers. Key stakeholders may include but should not be limited to groups that fulfill the following roles within the organization:

- Accounting
- Asset management
- Budgeting and finance
- Capital planning
- Fare collection
- Information technology
- Insurance
- Maintenance
- Operations
- Operational technology
- Procurement
- Quality assurance/quality control
- Safety and security
- SCADA

Systems asset hierarchies must be comprehensive and account for any overlap with other systems or asset categories (for example, networks and data centers as discussed in Section 3.2). The system architecture establishes these boundaries, which must be reflected in associated asset hierarchies to avoid overlap or duplication. It is critical for asset inventory purposes that systems' boundaries are clearly delineated and that assets shared by multiple systems are accounted for only once in hierarchies and inventories.

A useful foundation for organizing systems assets is a hierarchy based on the system function, or what the system and its parts are designed to perform. Systems are commonly a combination of disparate parts dispersed through a large service area that are operated and maintained by departments subject to organizational changes. Function can provide a stable, straightforward starting point on which to build hierarchies. Agencies can then adjust their hierarchies to meet specific needs, incorporating additional attributes, such as location or owner.

To develop an asset hierarchy based on function only, consider the components of the system (subsystems and system elements) and how they would be arranged in a functional parent-child relationship:

1) Group assets by primary function
2) Within each primary function group, list each secondary function group
3) Within each secondary function group, list the individual (or groups of identical) assets

Figure 4-2 depicts this process of developing a generic functional hierarchy by breaking down one of the primary functions to the individual asset level.

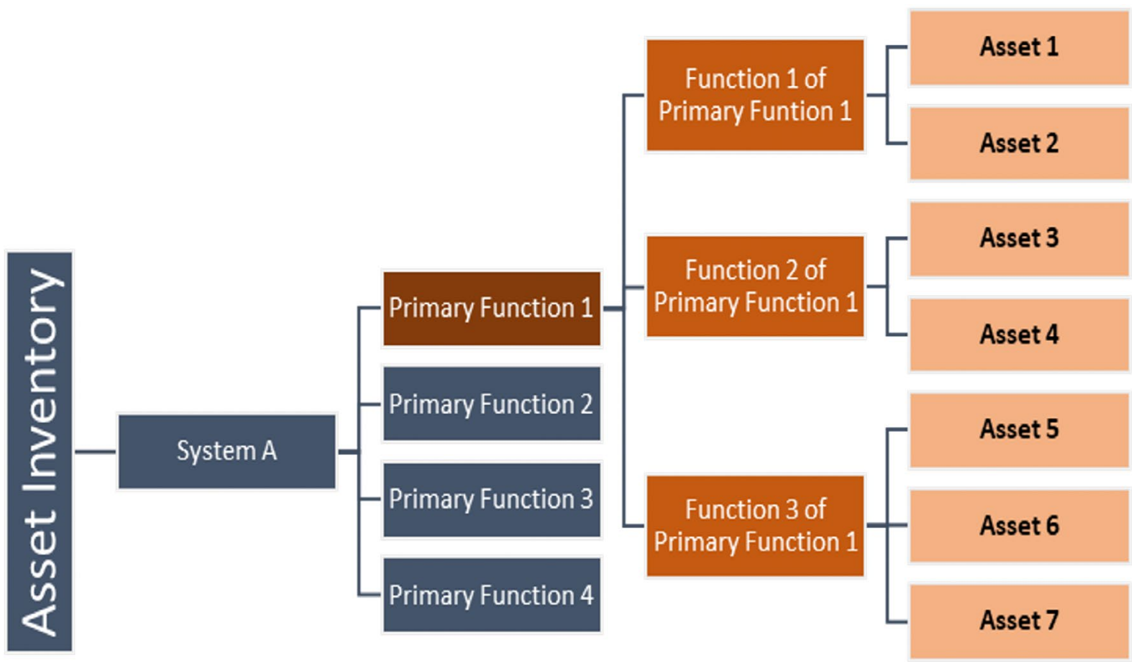
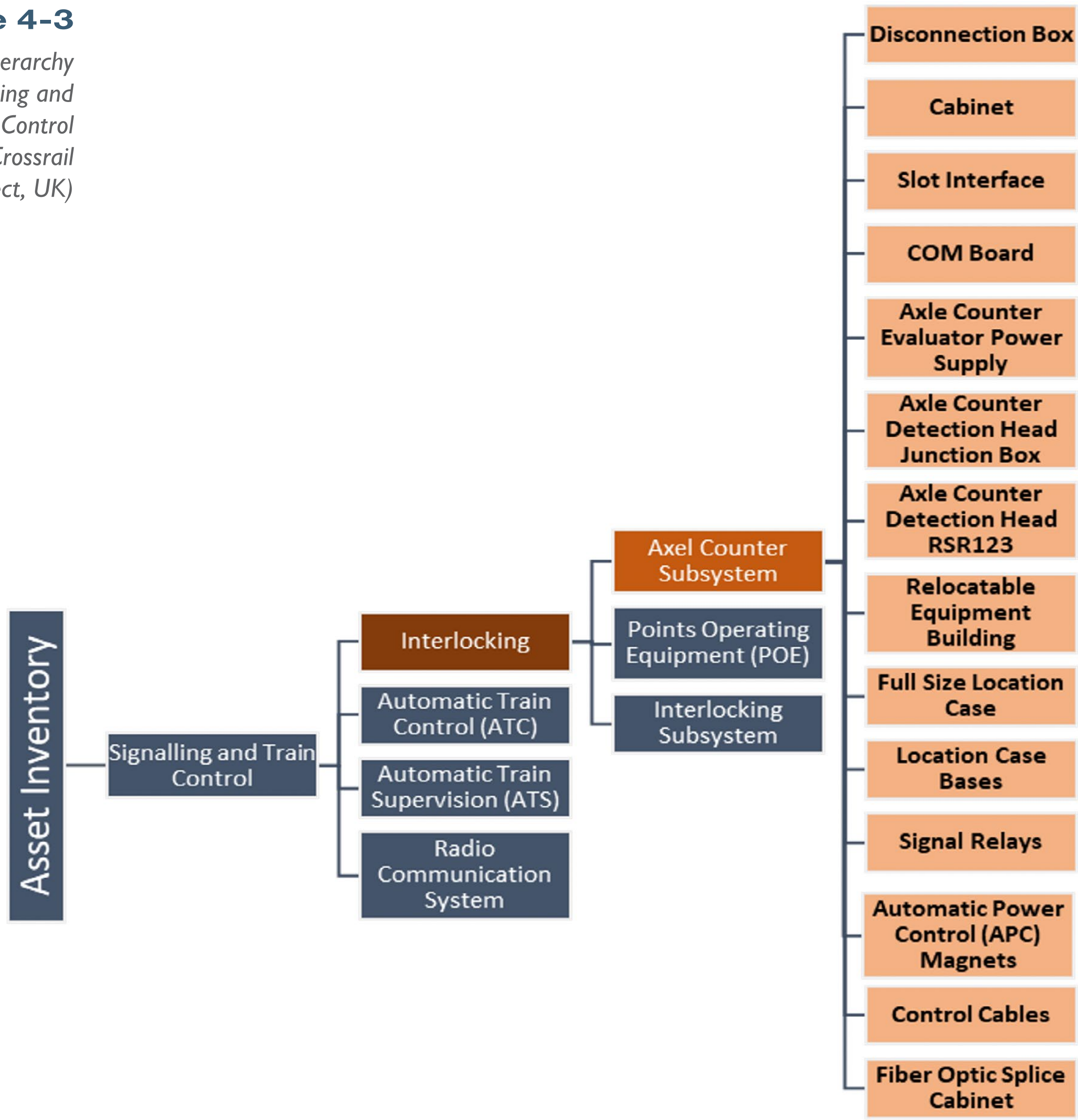


Figure 4-2 *Generic Hierarchy for "System A"*

Figure 4-3 illustrates how this process can be applied to a transit system's assets using a signaling and train control system as an example parent system. This example includes four primary function groups. To illustrate the process, the interlocking primary function group is segmented into its secondary function constituent parts. Finally, the Axel Counter Subsystem secondary function group is separated into individual assets, representing the lowest maintainable unit in the inventory.

Figure 4-3

Example Hierarchy for Signaling and Train Control System (Crossrail Project, UK)



4.5 Examples of Systems Asset Hierarchies

This subsection presents examples of asset hierarchies for the transit system asset classes included in this handbook to illustrate different approaches to organizing subsystems and elements. Hierarchies can vary in design, depth, and complexity based on several factors, including system functions, maintenance protocols, organizational structure, reporting requirements, as well as present and future needs of users.

The examples provided are not intended to serve as templates, but to demonstrate how subsystems and system elements can be organized in a top-down structure as an aid for transit agencies in their efforts to develop, shape, and refine their asset inventories. In this process, agencies will need to account for agency-specific factors that are applicable to their unique systems. Figure 4-4 shows the six asset classes for which this subsection provides hierarchy examples.

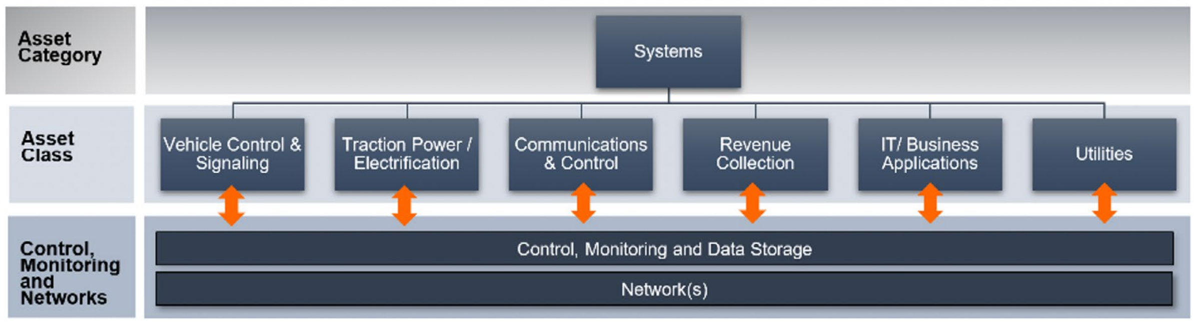


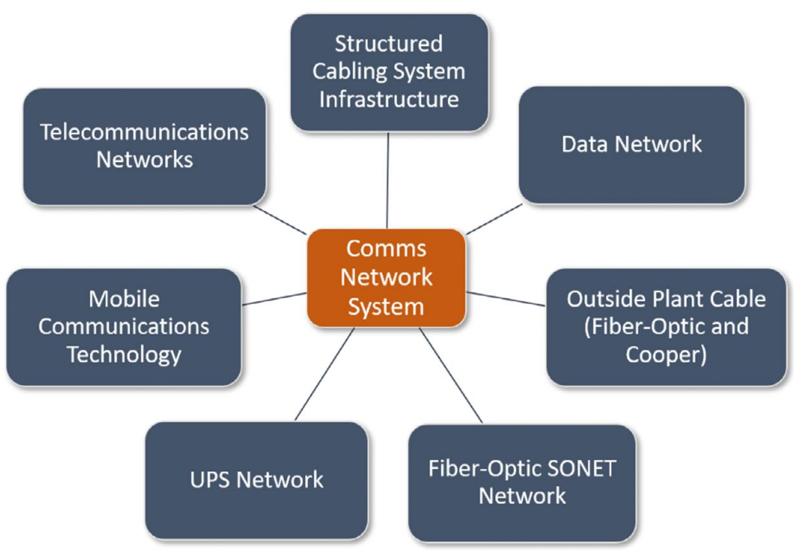
Figure 4-4 *Transit Systems Asset Classes and Control and Networked Support Systems*

4.5.1 Example Hierarchy of a Network Supporting Networked Systems

The network is the critical medium by which all subsystems and system elements of a system of interest are linked. Figure 4-5 shows a seven-building-block example configuration for a transit communications network. As indicated earlier, agencies developing their asset inventories may choose to classify and organize their assets for inventory purposes by function, asset type (grouping similar assets), organizational structure (who manages and maintains the assets), or location. The example provided in this subsection shows how the communications network subsystems hierarchies can be influenced primarily by function, but also by location or asset type.

Figure 4-5

Sample Building Blocks of a Communications Network System



The following is a brief description of the communications network building blocks included in this example.

1) **Structured cabling system infrastructure (Figure 4-6):** This group incorporates all the cabling that connects the critical data center and control center to subordinate nodes through which the cabling system traverses. These subordinate nodes include communications rooms, communications hubs, and intermediate distribution frame (IDF) closets.
2) **Data network (Figure 4-7):** This group includes asset devices that control data movement and security, including firewall devices, routers, switches, and wireless equipment such as controllers and access points. The data network is divided into three main groups: corporate network, rail network, and wireless network.
3) **Outside plant cable (fiber-optic or copper) (Figure 4-8):** This set of assets includes the cabling network outside the agency's buildings.
4) **Fiber-optic SONET network (Figure 4-9):** The SONET[4] (synchronous optical network) is used to transmit a large amount of data over relatively large distances using fiber-optic cable. With SONET, multiple digital data streams can be transferred at the same time. This arrangement divides the SONET network into four elements: multiplexer[5] chassis, cards, optics, and network management system.
5) **Uninterrupted power supply (UPS) network (Figure 4-10):** UPS devices provide battery backup when the electrical power fails or drops to an unacceptable voltage level. Small UPS systems provide power for a few minutes, enough to power down a computer in an orderly manner, whereas larger systems have enough battery for several hours. The example provided in this subsection classifies the UPS devices into four groups: three based on location (facilities, stations, and miscellaneous) and battery backup.

[4] SONET is a communication protocol used to transmit multiple streams of large amounts of data simultaneously over long distances using fiber-optic cable. It is a "synchronous" network because a single primary reference clock times the transmission of data over the entire network. Advantages to using a SONET include low electromagnetic interference and high data rates. Geeks for Geeks.

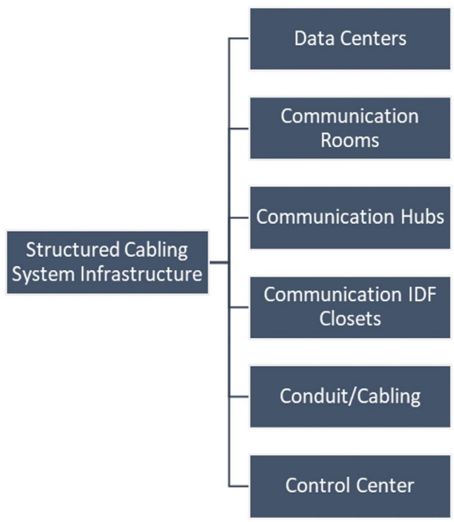
[5] Multiplexer is a device allowing one or more low-speed analog or digital input signals to be selected, combined and transmitted at a higher speed on a single shared medium or within a single shared device. Thus, several signals may share a single device or transmission conductor such as a copper wire or fiber optic cable. Techopedia.

6) **Telecommunications Networks (Figure 4-11):** These assets support the channel banks,[6] which allows with their processing power converts a bank of up to 24 or 32 individual channels to a digital and then analog format.

7) **Mobile communications technology (Figure 4-12):** This is the critical group of assets that allows the network to be connected to moving vehicles. This arrangement divides the assets of this example into three main groups based on the type of vehicles they serve: bus technologies, rail technologies, and nonrevenue vehicle technologies.

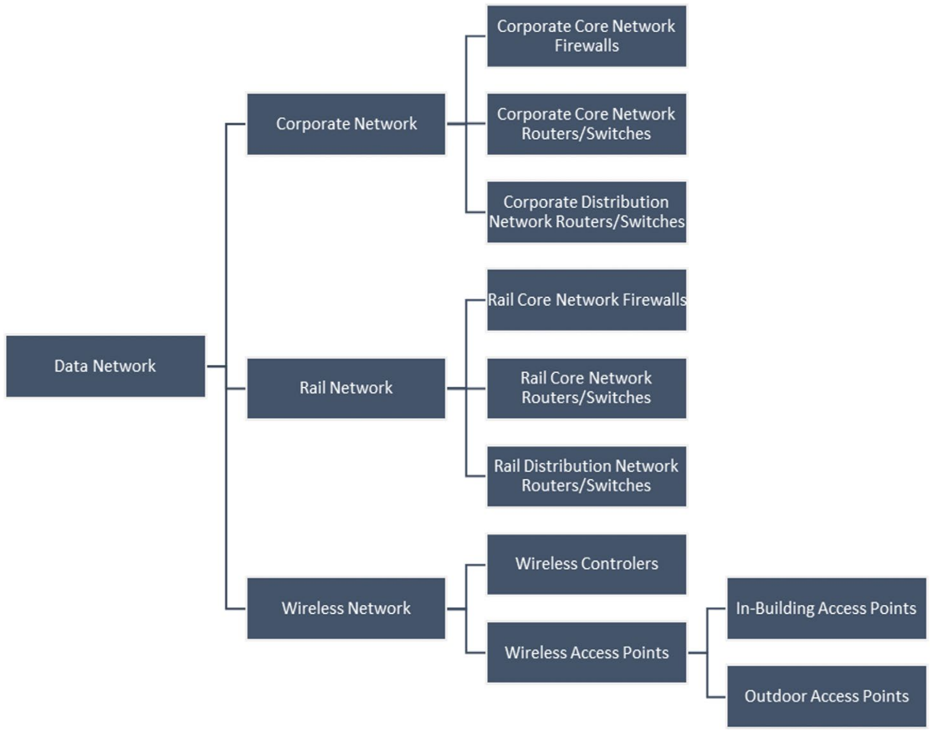
Figure 4-6

Example Hierarchy for Structured Cabling System Infrastructure (Network System)



[6] A channel bank is a device used for multiplexing or demultiplexing a group of communication channels, including analog or digital telephone lines combined as a channel of higher bandwidth or digital bit rate. Channel banks are located in a telephone exchange or enterprise telephone closet, where individual telephone lines are separated from high-capacity telephone trunk lines originating from a central telephone office or enterprise private branch exchange (PBX). Channel banks connect multiple voice channels through multiplexing and voice digitalization and are important digital communication transmission devices. A channel bank is referred to as a bank because of its processing power that converts a bank of up to 24 or 32 individual channels to digital and then analog format. These channels contain T1/E1 circuits. A channel bank may also multiplex channel groups into higher bandwidth analog channels. There are different types of channel banks. Every channel bank contains formatting, which allows a user to achieve the desired results. Channel banks types include T1 circuits, each composed of 24 channels, and D4 channel banks containing digital signal level one (DS-1) signals. The DS-1 ensures that data is formatted with D4 format. Other types of channel banks are D2, D3, and digital carrier trunk. These channels are widely used by most telephone companies. Techopedia.

Figure 4-7 *Example Hierarchy for Data Network (Network System)*



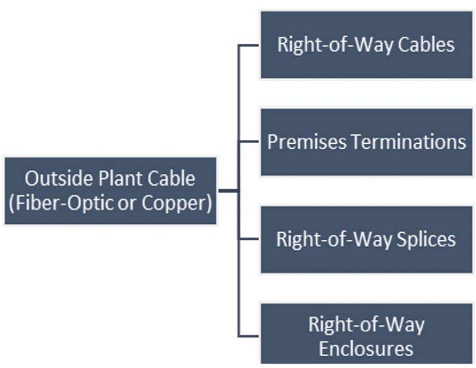


Figure 4-8 *Example Hierarchy for Outside Plant Cable (Fiber-Optic or Copper) (Network System)*

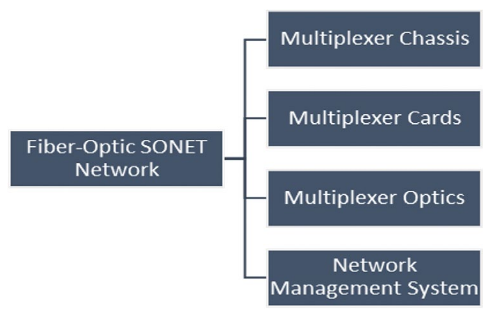


Figure 4-9 *Example Hierarchy for Fiber-Optic SONET Network (Network System)*

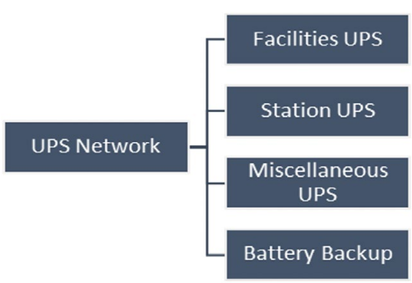


Figure 4-10 *Example Hierarchy for Uninterrupted Power Supply Network (Network System)*

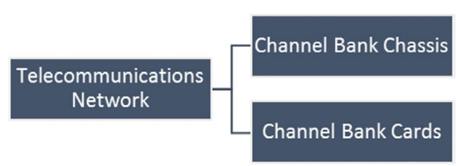
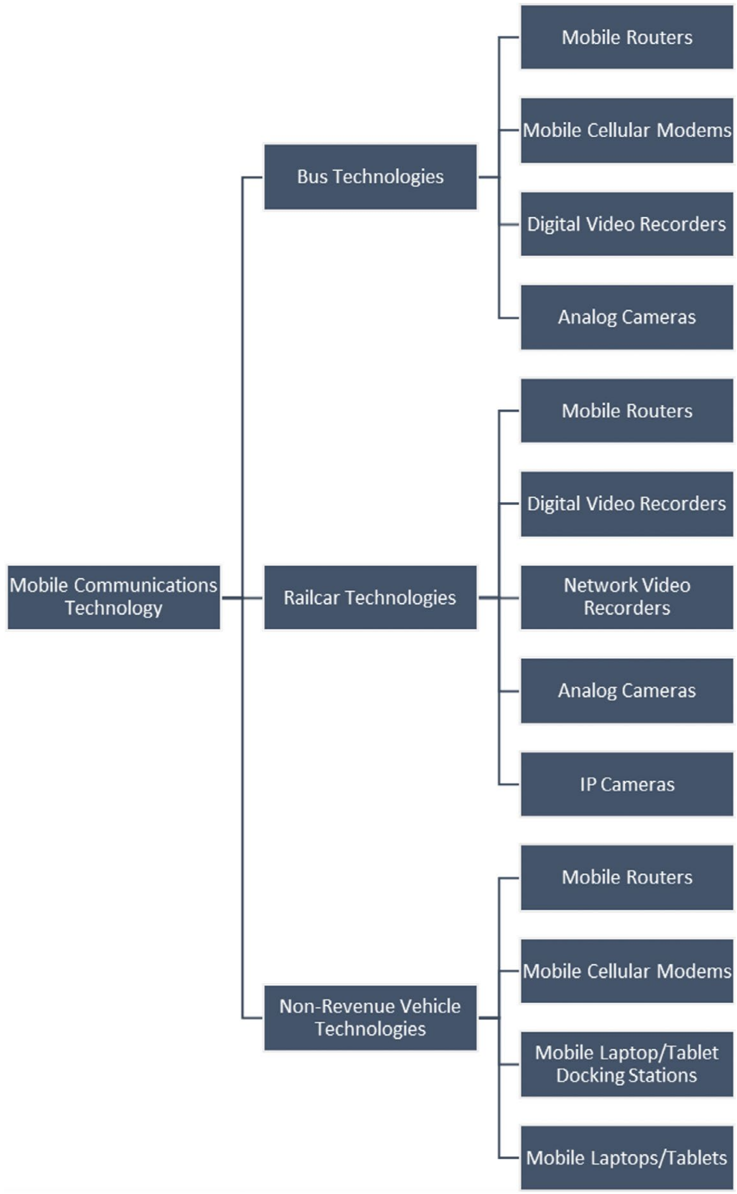


Figure 4-11 *Example Hierarchy for Telecommunications Network (Network System)*

Figure 4-12

Example Hierarchy for Mobile Communications Technologies (Network System)



4.5.2 Examples of Asset Class Systems

4.5.2.1 Vehicle Control/Signaling System Example Hierarchies

Figure 4-13 presents a generic functional hierarchy for a rail signal system. This example is based on the AREMA (2019) *Manual for Railway Engineering* detailed description of the functional elements of a high-speed rail signal system. In practice, this type of arrangement must be adjusted to conform to the specific conditions of an agency's system. Figure 4-14 shows a generic train control hierarchy example based on the Transit Economic Model Requirements (TERM) framework.

Figure 4-13

Example Hierarchy for a High-Speed Rail Signal System Based on AREMA's 2019 Manual for Railway Engineering *System Description*

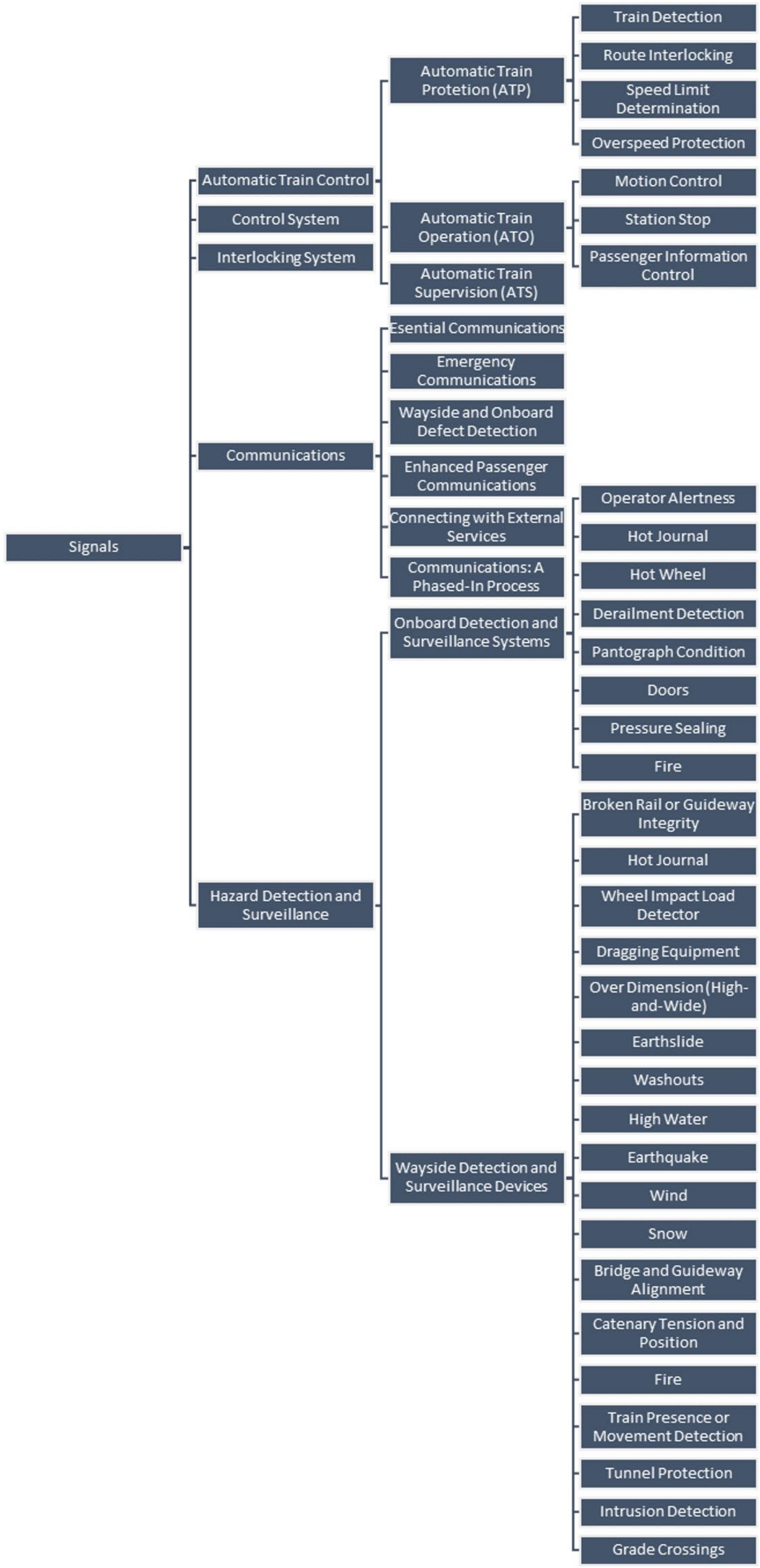
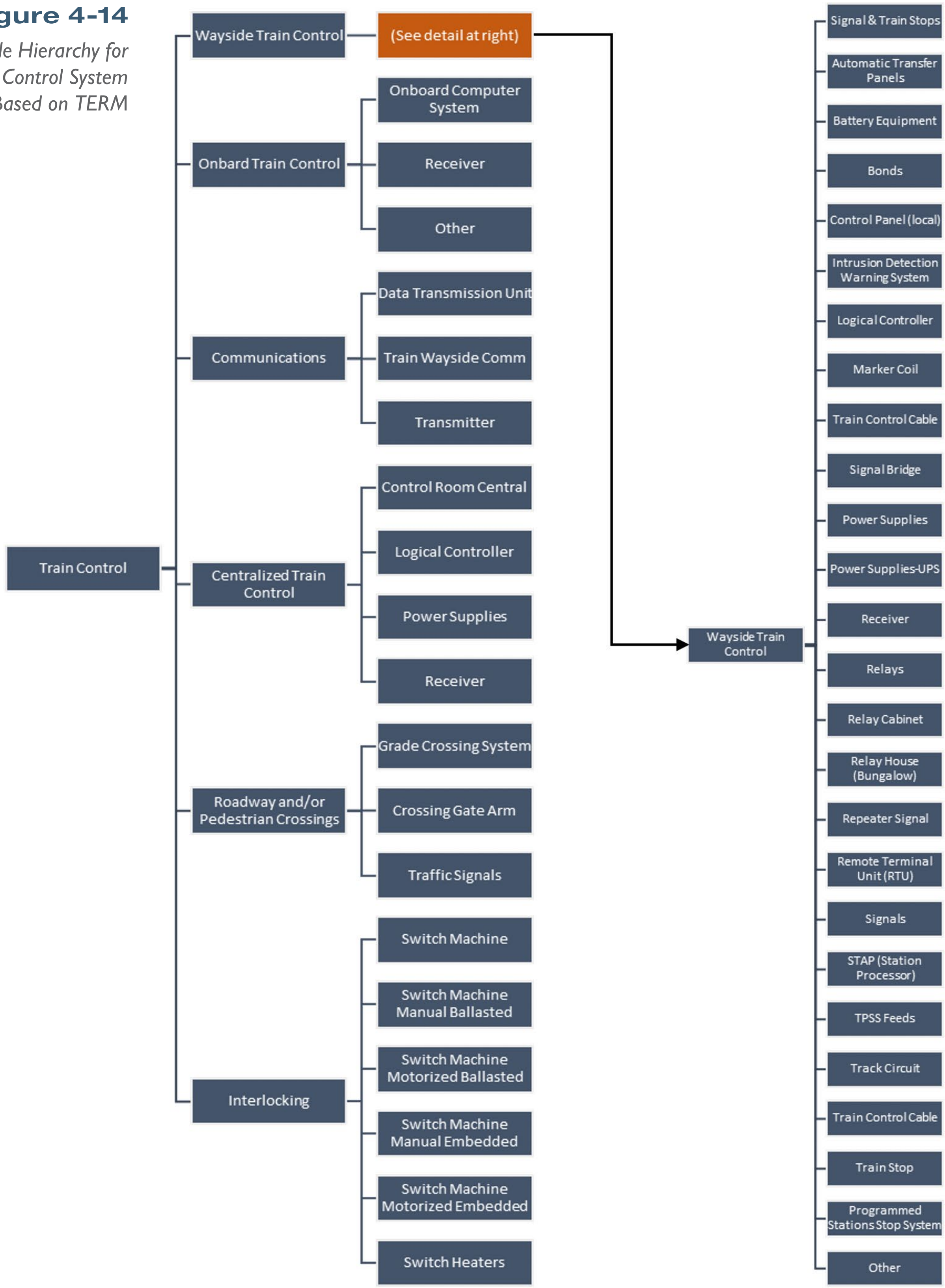


Figure 4-14

Example Hierarchy for Train Control System Based on TERM



4.5.2.2 Traction Power/Electrification System Example Hierarchy

Figure 4-15 depicts a subway traction power/electrification systems hierarchy example. This hierarchy includes two types of power delivery options: contact (or third) rail and overhead catenary system (or overhead contact system). This inventory hierarchy integrates two modes using different power delivery methods (third rail for heavy rail and overhead catenary for light rail). There are cases, however, in which heavy rail systems might be powered by both third rail and overhead catenary. To illustrate the path down to the system element (lowest maintainable unit in the inventory), the substation and auxiliary power substation function groups have been completely segmented.

Figure 4-15

Example Hierarchy for Subway Traction Power/Electrification Systems

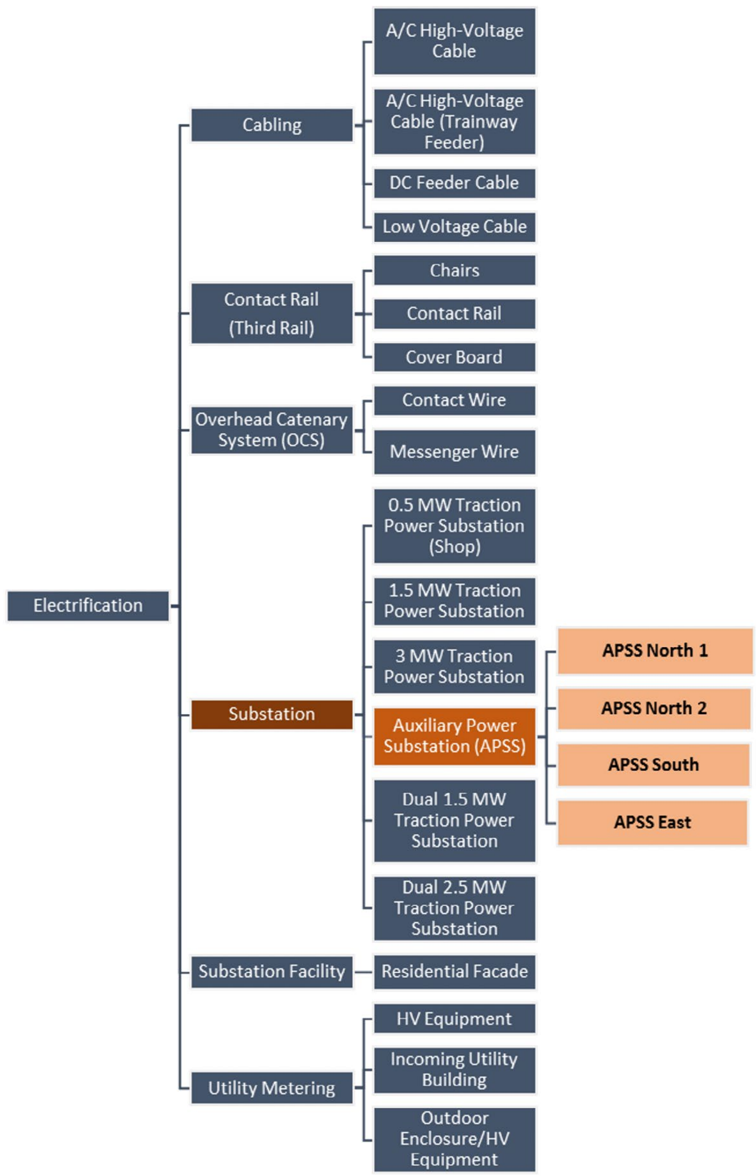


Figure 4-16 displays a commuter rail traction power electrification system hierarchy example. The system is divided into the following four subsystems/asset groupings: (1) traction power substation (TPSS) system which includes the various types of equipment housed within the TPSS; (2) substation facilities which encompass the building structures and their supporting systems (lighting, fire protection, intrusion detection, etc.); (3) SCADA system (see detail under Figure 4-17); and (4) traction power distribution systems which is further subdivided into third rail and negative return.

Figure 4-16

Example Hierarchy for a Commuter Rail Traction Power/ Electrification System

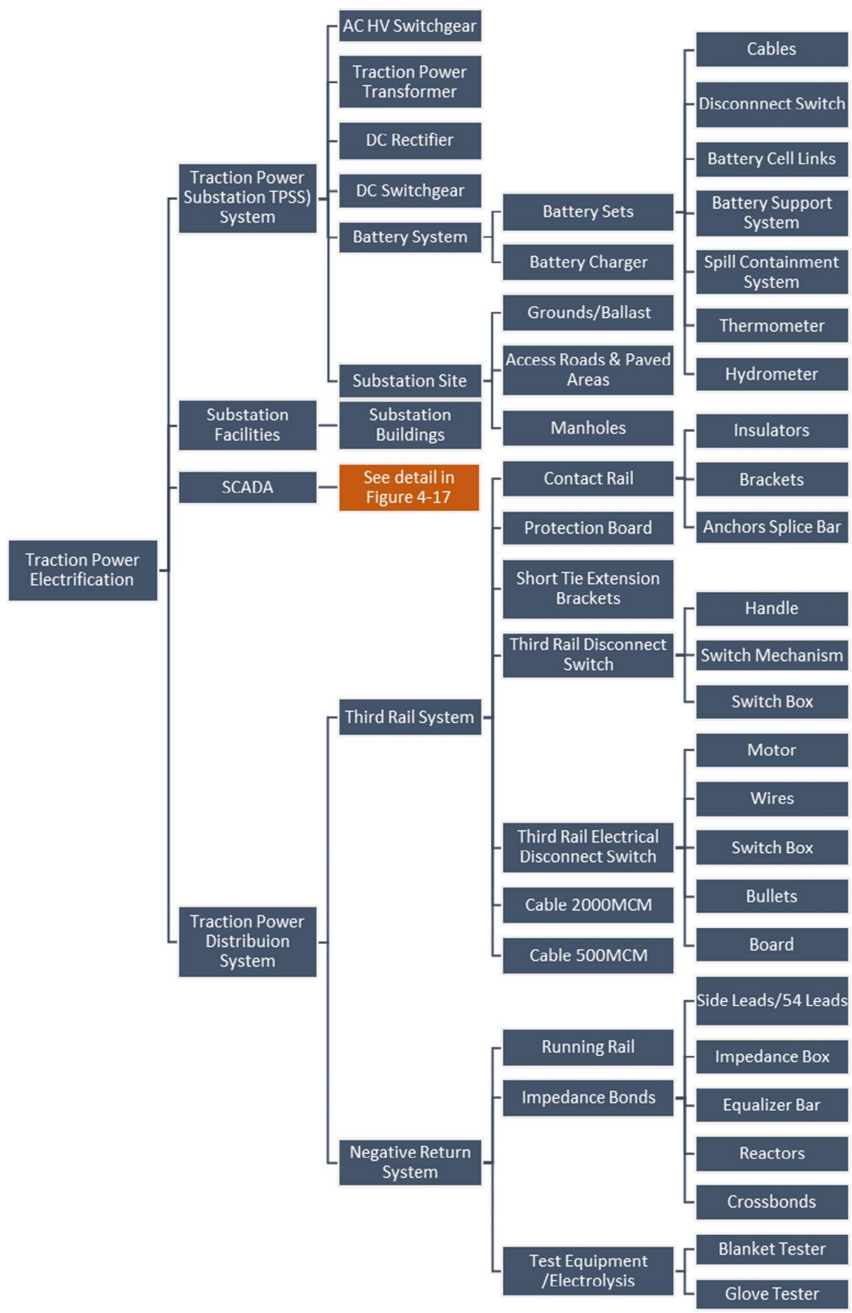
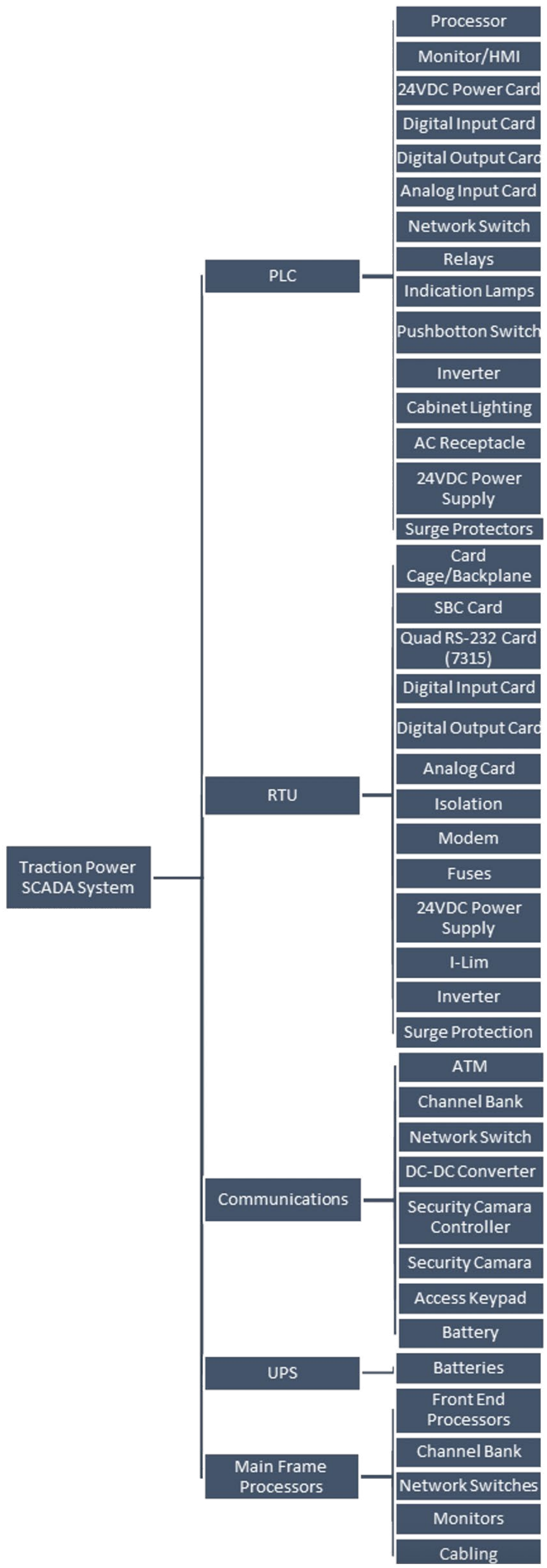


Figure 4-17

Example Hierarchy for a Commuter Rail Traction Power Electrification System—SCADA System Detail



4.5.2.3 Communications and Control System Example Hierarchies

Communications and control systems perform critical support functions for transit agencies. These systems extend beyond the boundaries of a single facility and sometimes cover the entire territory served by the transit operator. Key system elements of these systems are commonly affixed to existing buildings (for example, stations, facilities, and parking garages) or to poles along the right-of-way but are also affixed to revenue and service vehicles. To operate, these systems are linked via communications networks. (See Subsection 3.2.)

Figures 4-18 through 4-23 show a series of hierarchy examples for selected communications systems. As explained in Subsection 3.2, the communications, fare collection, and tunnel support hierarchy examples included in this subsection and in Subsections 4.4.2.4 and 4.4.2.6 have a similar general configuration. As shown in Figure 3-2, each of these systems can be subdivided into three distinct subsystems or asset groups: (1) Control, Monitoring, and Data Storage (which includes the data center, workstations, and control center); (2) Networks (the medium on which the data travels); and (3) Primary Function Systems (such as CCTV and PA). To be operational, the transit systems for end-use operations elements need to “plug into” a network, which will link them to the control, monitoring, and data storage subsystems. The hierarchy examples in this subsection include the primary function systems and the specialized software component of each system that is commonly located in the servers of a data center.

Figure 4-18 displays an example of a CCTV system inventory hierarchy. The system hierarchy is split into three main groups: Video Management System, Video Analytic Systems, and Cameras. The video management system includes the system servers, video recorders and various licenses. The video analytic systems include the systems servers and the corresponding licenses. The third group lists all cameras broken down by type.

Figure 4-18

Example Hierarchy for a CCTV Video System

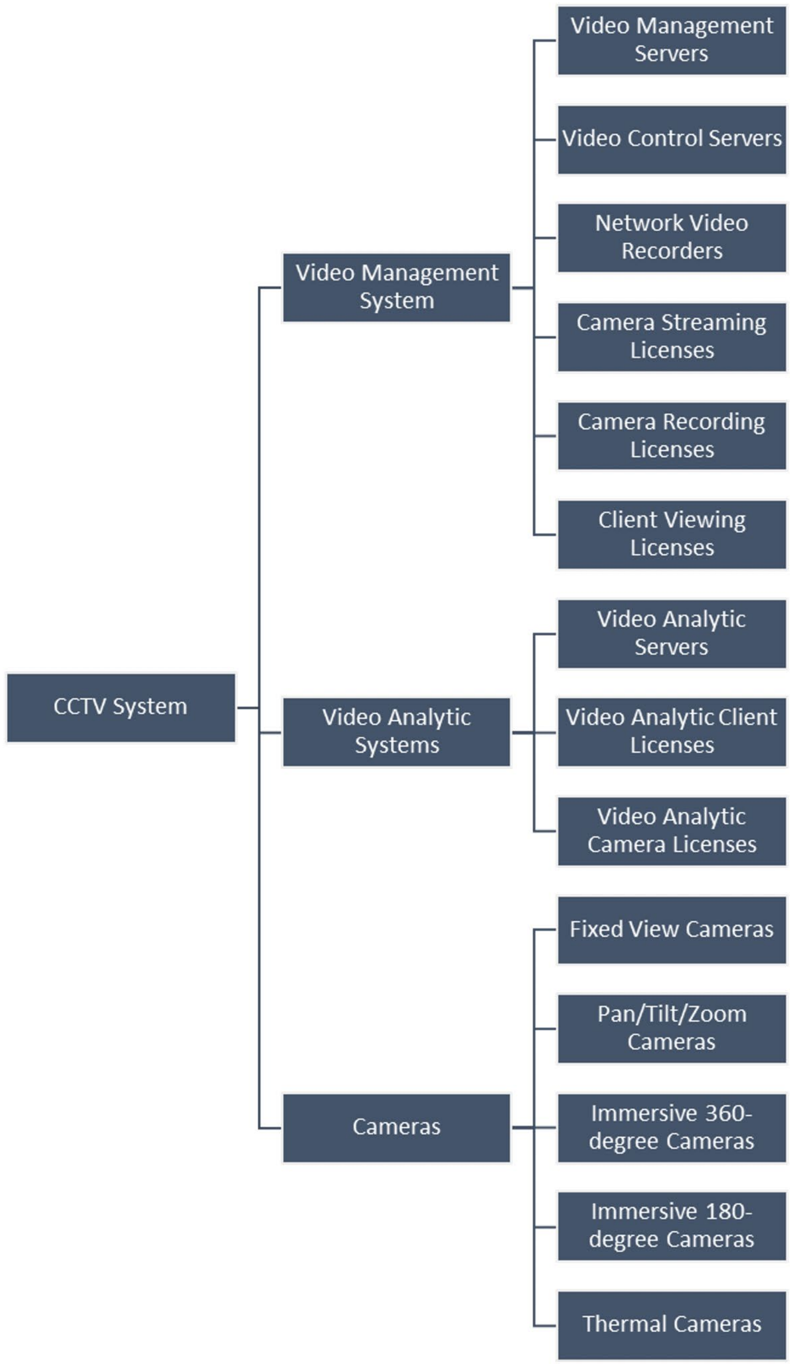


Figure 4-19 shows an example of a PA system inventory hierarchy. This system displays a straight-forward configuration that includes primary, secondary and remote PA head-end hardware and software. It also includes remote PA microphone consoles and six speaker types.

Figure 4-19

Example Hierarchy for a Public Address System

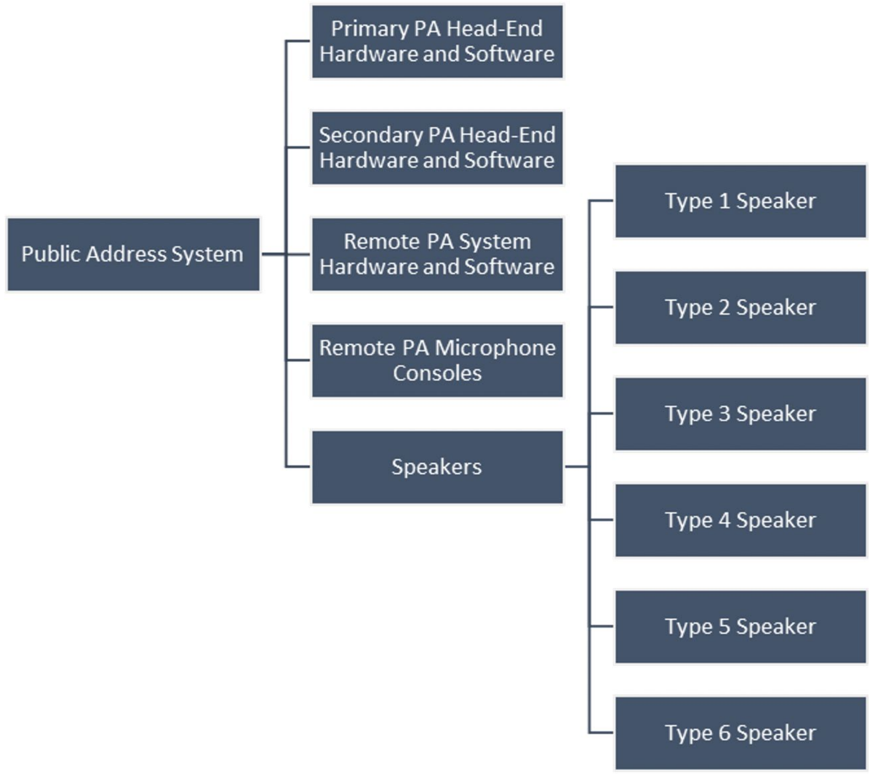


Figure 4-20 displays a public announcement system, also known as audio visual paging system (AVPS). The system comprises the following key subsystems and/or asset classes: (I) Server (where the system software resides); (2) Audio Unit, which encompasses fiber optic converter, preamplifier and audio amplifier, (3) AVPS Sign, which includes visual display assets; (4) Network Switch (which may be used to link network modules); (5) AVPS Console (hardware that hosts the system control and monitoring capabilities); (6) Speaker; (7) Speaker Pole; and (8) Noise Sensing Microphone.

Figure 4-20

Second Example Hierarchy for a Public Address System

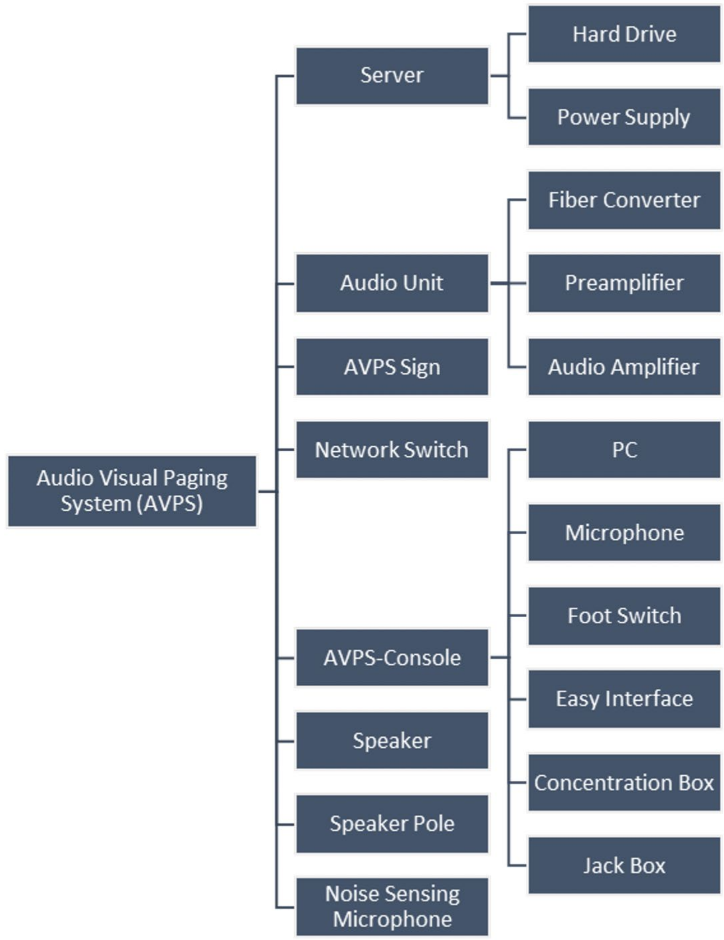


Figure 4-21 displays a radio system inventory hierarchy, which has a very straightforward configuration composed of eight subsets: transmitter, receiver, and simulcast[7] sites; primary and secondary radio head-ends; subway distributed antenna system (DAS), which includes DAS BDAs[8]; radio consoles; and four types of radios.

Figure 4-22 shows a radio system hierarchy example. The system is bifurcated on two streams: the base station segment, which hosts the radio base equipment, and the mobile segment, which allows vehicles communicate with the rest of the radio network.

[7] Simulcast (simultaneous broadcast) is the broadcasting of programs or events across more than one medium or more than one service on the same medium at exactly the same time (simultaneously).

[8] BDA stands for Bi-Directional Amplifier system, which is a signal boosting solution designed to enhance in-building radio frequency (RF) signal coverage for public safety radio. This system supports crews when in-building radio signals are weakened by structures such as concrete and metal. www.securityandfire.honeywell.com.

Figure 4-21

Example Hierarchy for a Radio System

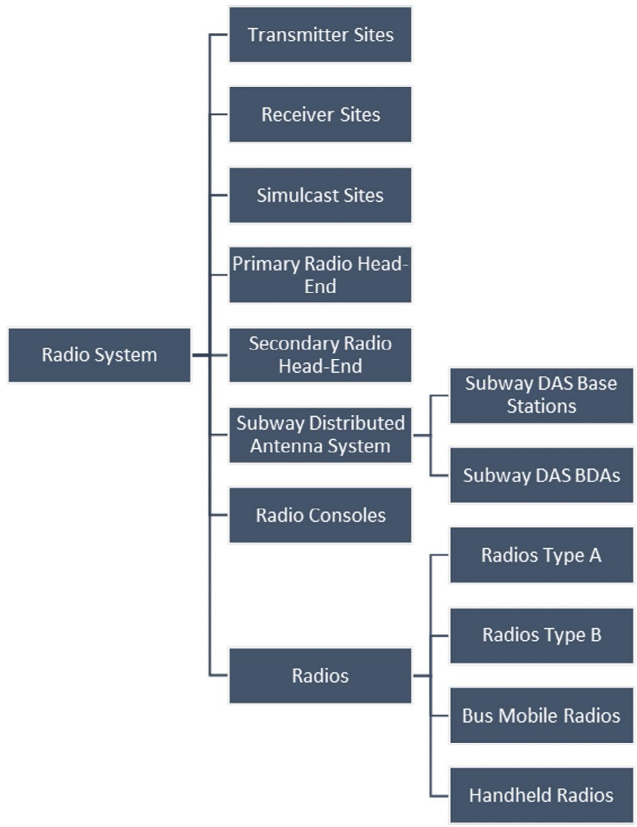


Figure 4-22

Second Example Hierarchy for a Radio System

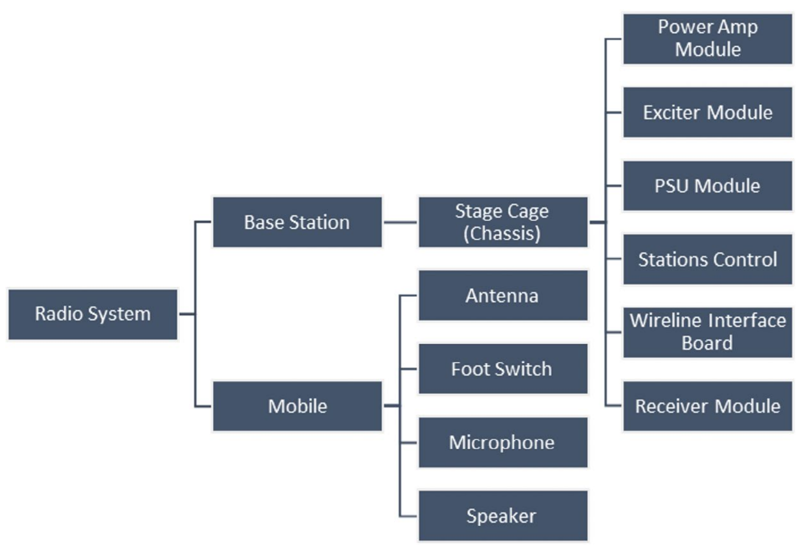
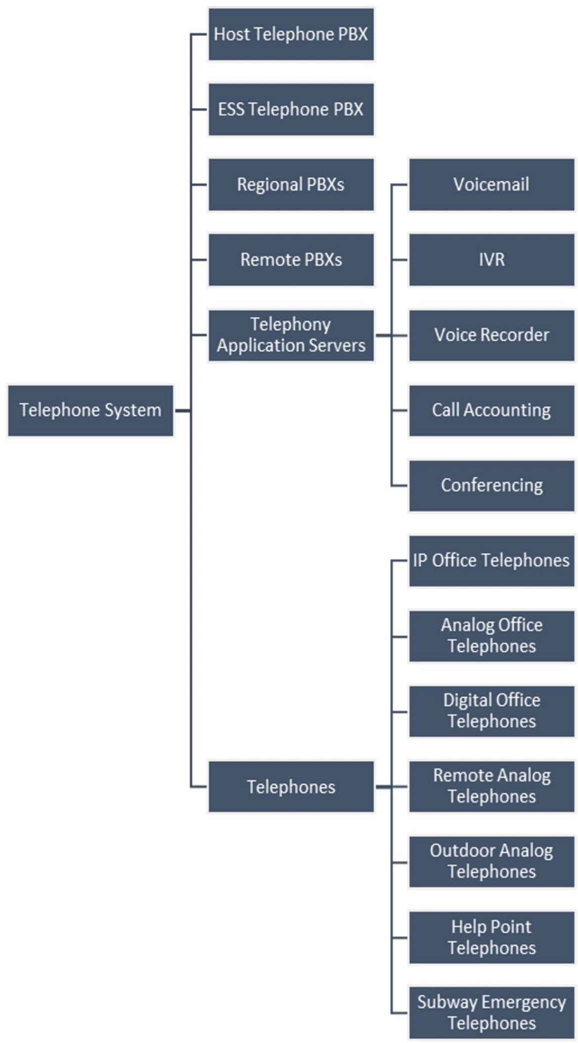


Figure 4-23 displays a telephone system inventory hierarchy. This system is divided into six distinct asset groups: Host Telephone PBX, Electronic Switching

System (ESS) Telephone PBX, Regional PBX, and Remote PBX,[9] Telephony[10] Application Servers (for five functions: voicemail, IVR,[11] voice recorder, call accounting, and conferencing), and Telephones (seven types).

Figure 4-23

Example Hierarchy for a Telephone System



[9] PBX stands for private branch exchange. It is a telephone system within an enterprise that switches calls between enterprise users on local lines while allowing all users to share certain number of external phone lines. The main purpose of a PBX is to save the cost of requiring a line for each user to the telephone company's central office. The PBX is owned and operated by the enterprise rather than the telephone company (which may be a supplier or service provider, however). PBXs used analog technology originally. Today, PBXs use digital technology (digital signals are converted to analog for outside calls on the local loop using "plain old telephone service" [POTS]). Nonetheless, PBX can include network switches that accommodate analog phones into the enterprise's digital PBX system. TechTarget.

[10] Use of technology applications to generate and receive telephone services such as voice recording, conferencing, etc.

[11] IVR stands for interactive voice response. It is an automated telephony system that interacts with callers, gathers information, and routes calls to the appropriate recipients. An IVR system accepts a combination of voice telephone and touch-tone keypad selection and provides the appropriate responses in the form of voice, fax, callback, email, and other contact methods. TechTarget.

Figure 4-24 encompasses a SCADA system inventory hierarchy. The system comprises eight modules—servers, remote terminal units[12] (RTUs) for substations, stations, facilities, subway zones and wayside, and two types of software.

Figure 4-24

Example Hierarchy for a SCADA System

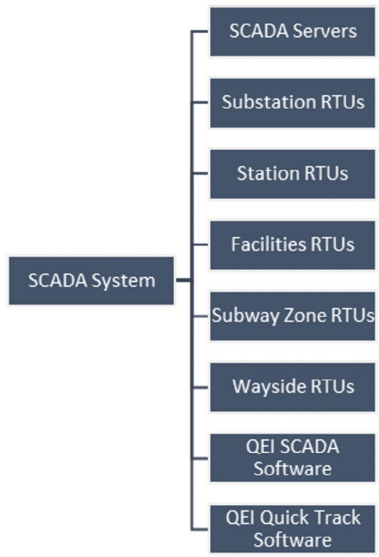
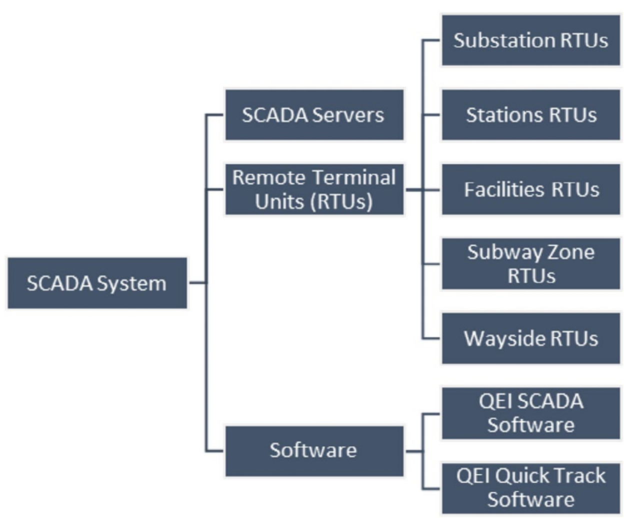


Figure 4-25 shows the SCADA system from Figure 4-23 arranged slightly differently. Instead of listing all asset types at one level, it shows a two-step arrangement that groups the SCADA system elements by function first (servers, RTUs, software), then groups the secondary supporting functions (RTUs by the environment in which they operate and software by type).

Figure 4-25

Modified Example Hierarchy for a SCADA System



[12] An RTU is a device installed at a remote location that collects data, codes the data into a format that is transmittable, and transmits the data back to a control center. An RTU also collects information from the master device and implements processes that are directed by the master. RTUs are equipped with input channels for sensing or metering, output channels for control, indication or alarms, and a communications port. www.webopedia.com.

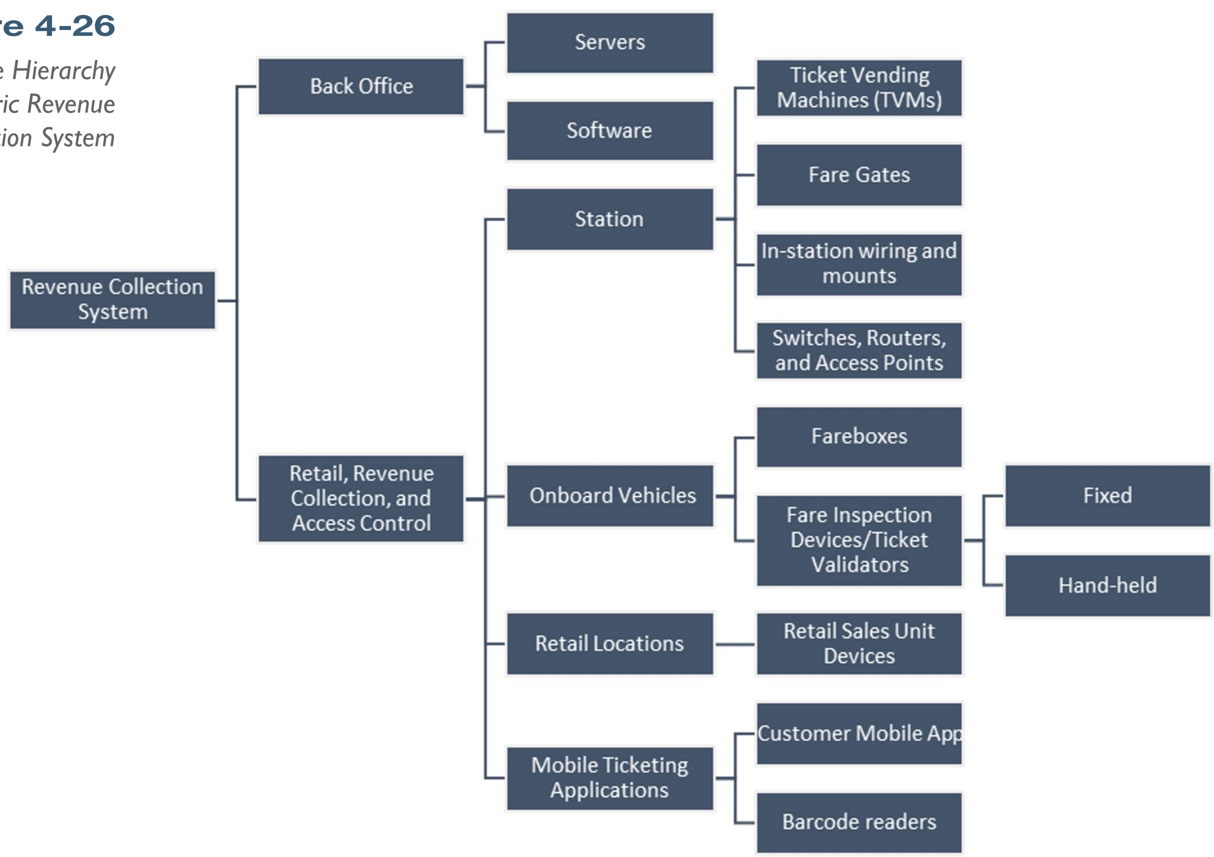
4.5.2.4 Revenue Collection System Example Hierarchy

Figure 4-26 shows a hierarchy for a generic revenue collection system. As in the communications systems examples (Subsection 4.4.2.3), to be fully operational, a revenue collection system needs to plug into a network that connects the various revenue collection devices to the control, monitoring, and data storage subsystems (see Figure 3-2).

The example provided below includes revenue collection primary functions, subsystems, and system elements and their corresponding software. The example divides the revenue collection system between back office equipment (servers and software) and hardware (retail, revenue collection, and access control). The hardware is then segregated by physical location (station, onboard vehicles, retail locations, and mobile ticketing applications).

Figure 4-26

Example Hierarchy for a Generic Revenue Collection System



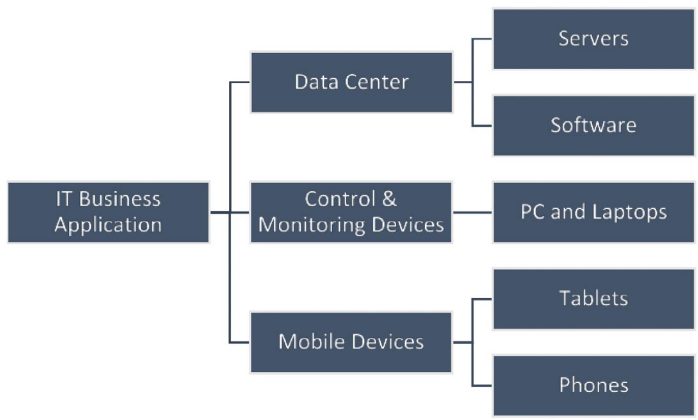
4.5.2.5 IT Business Applications System Example Hierarchy

Figure 4-27 shows a generic hierarchy for business applications. As noted in Section 3.2, any new business application will connect to an existing network that links to the control, monitoring, and data storage system elements (Figure 3-2).

The basic business application configuration shown in Figure 4-27 encompasses three main groups: data center elements, control and monitoring devices, and mobile devices. The software and any data storage needed to support the business application are physically located in the system servers. Servers are commonly hosted in an agency data center, although they can be accessed from third-party providers via cloud computing services. Software is the computer program(s) with a set of business rules that govern the business application. The second group of assets is composed of the computer terminals that operate and monitor the business application (personal computers, laptops). The third element represents a grouping of mobile devices (or hardware) that may support the business application. For example, an enterprise asset management system might link mobile devices to the business application to allow operations and maintenance personnel to enter information collected in the field directly into the business application database(s).

Figure 4-27

Example Hierarchy for IT Business Applications

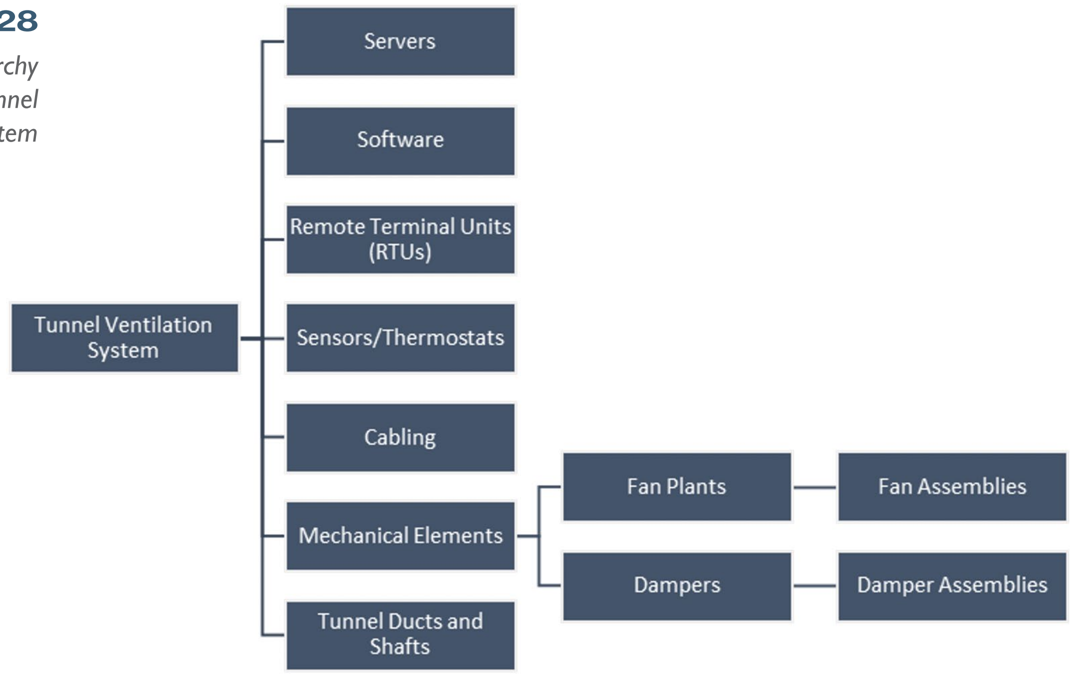


4.5.2.6 Tunnel Support System Example Hierarchy

Figure 4-28 shows a hierarchy for a generic tunnel ventilation system. The system is subdivided into six subsystems or asset groups based on their function. The first two modules include the servers and software needed to control and monitor the system. The third module incorporates the RTUs that help administer the business rules of the system at various remote locations. The fourth module, sensors and thermostats, help monitor air quality and alert the system and operators of potential safety hazards along the tunnel right-of way. The fifth module incorporates mechanical systems that control the flow of air in and/or out of the tunnels (that is, fan plants and dampers). The sixth and final module includes tunnel ducts and shafts, which are the physical infrastructure elements that support the tunnel ventilation system.

Figure 4-28

Example Hierarchy for a Generic Tunnel Ventilation System



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Section 5

Systems Performance Management and Investment Prioritization

5 Systems Performance Management and Investment Prioritization

This section presents general concepts related to systems asset performance management and investment prioritization and targeted practices associated with the six transit systems asset classes discussed in this handbook. Given the complexity of systems and diversity of their applications, performance evaluations and condition assessment approaches have not been standardized. The concepts and practices presented herein represent examples of systems engineering and transit industry approaches to managing system asset performance and prioritizing capital investments.

Performance management entails the monitoring, evaluation, and improvement activities critical to preventing or mitigating the deterioration of performance of systems, subsystems, and critical individual assets as well as managing their risk of failures, which may impact safety and reliability. Continuous monitoring of subsystems and system elements and associated management activities is necessary to ensure that the level of service of large and complex systems is maintained, particularly in operating environments with rapidly-evolving functional requirements and technologies.

A robust life cycle asset management program coupled with efficient performance management and data gathering can serve as a foundation for an investment prioritization process that fully supports maintenance and renewal activities and allows systems operators to obtain the best value from their systems by providing the required level of service at the lowest life cycle cost.[13] This section presents key drivers that influence investment prioritization for maintenance, improvement, and renewal activities associated with TAM systems.

5.1 Special Considerations for Systems Asset Management

Subsystems and system elements of transit systems vary greatly in size, complexity, design life, cost, and deterioration or degradation rate. From an operational and maintenance standpoint, systems are in a state of continuous activity. To ensure that systems' required levels of service are met, critical

[13] Lifecycle costing is the analysis of the cost implications for a system, subordinate system, or system element over the agency's period of responsibility. When system performance is met, the lowest life cycle cost represents the best value delivered to the agency. Lifecycle costing is also called "total cost of ownership" (IAM, 2015a).

subsystems and system elements are constantly monitored, maintained, and upgraded. In much the same way, much attention is given to the critical interactions between and among subsystems and system elements, as they are vital to system performance. Even without changing the overall system requirements, system managers are continuously confronted with the necessity to upgrade or replace system elements. In such a dynamic environment, system managers must ensure the interoperability of newer system elements with "legacy" system elements while preserving the functional and operational qualities of the system. When subsystems or system elements are upgraded or replaced to meet enhanced or expanded capabilities for the entire system, the level of complexity increases, as the new and "legacy" system elements must operate and interface in synchronized fashion to deliver enhanced system capabilities.

5.1.1 Systems Asset Class Strategy

By joining efforts, a systems management team and its asset management counterpart can reap mutual benefits. Collaboration can help connect the system management team, whose focus is to ensure system functionality, with the broader agency-wide context, such as organizational, funding, legal, and compliance aspects. The asset management team, on the other hand, can gain vital technical insight into current and future operational and maintenance issues affecting overall system performance.

Further, systems and asset management teams can work collaboratively to develop highly-specialized asset class strategies (ACS) that help ensure the viability of systems for the remainder of their life cycles. In alignment with the agency's asset management strategy, the ACS establishes objectives and a roadmap of actionable items for a specific asset class, including future capabilities and performance targets. An ACS typically encompasses the following elements and concepts:

- Alignment with the agency's strategic plan, as well as other organizational policies and strategies
- Baseline of current conditions, performance, utilization, and capabilities
- Adoption of a *whole life cycle* and *total cost of ownership* management concepts
- Consideration of requirements and expectations of stakeholders
- Forecast of future needs to determine whether system requirements must be adjusted
- Identification of constraints, such as funding and personnel availability and skills
- Consideration of external factors that might impact system operations or requirements (for example, the emergence of new technologies, fluctuations in demand for services, economic conditions, changing customer behavior)

- Incorporation of relevant feedback from evaluation processes to make the necessary adjustments to maintenance and renewal activities with the goal of optimizing performance
- A decision-making framework with risk-based criteria

5.1.2 Disciplines and Processes that Support Systems Life Cycle Activities

Systems life cycle activities can also be supported by various specialized disciplines and processes, such as systems engineering, reliability engineering, and configuration management:

- **Systems engineering** focuses on how to design and manage complex engineering systems over their life cycles. Systems engineering addresses reliability, availability, maintainability, and safety requirements. One area of focus is interfaces between new and older systems subsystems and systems components (IAM, 2015b).
- **Reliability engineering** systematically applies engineering principles and techniques throughout an asset's life to ensure that a system or device can perform a required function under given conditions for a given time interval. This discipline focuses on identifying potential reliability problems as early as possible to take actions to preserve the system's level of service. Reliability engineering looks not only at the performance of individual system elements, but also at the performance of the system as a whole because it does not always require an individual part of a system to fail for the overall system to not perform as designed or required. This constitutes a loss of system reliability.
- **Configuration management** identifies, records, and helps manage the functional and physical attributes of physical assets, software, and related documentation. It tracks the links between the components of a system. A central role of this process is to provide a systematic control of changes to the identified attributes of items for the purpose of maintaining integrity and traceability throughout the asset's life cycle (IAM, 2015b).

5.2 Introduction to Systems Performance Management

Obtaining the most value from a system requires a comprehensive approach that spans its entire life cycle. However, this section focuses on the utilization, support, and retirement stages of the system life cycle (highlighted in Figure 5-1) when most performance monitoring and reinvestment activities take place. (See Section 2 for more information on the system life cycle stages.) In addition, the *Asset Management Guide Supplement 2019* (Section 4 for Revenue Collection; Section 5 for Traction Power, Train Control, Communications, and Security) should be consulted for related transit systems management information across all life cycle stages.

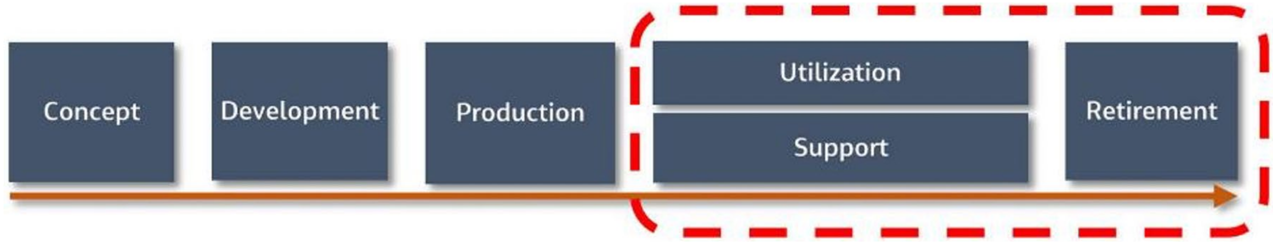

Figure 5-1 *Generic System Life Cycle Stages*

As a system provides the required services (utilization stage), it can simultaneously be undergoing maintenance activities aimed at preserving or mitigating the deterioration of the system performance (support stage). These activities include inspection and testing as well as preventive and corrective maintenance. Data-gathering related to these activities can help support the planning of subsequent maintenance and renewal activities (including retirement stage) and can be instrumental in identifying and prioritizing investments.

Understanding where a system is in its life cycle and which maintenance or renewal activities are required can be accomplished through monitoring and evaluating system performance, or how well the system is providing the associated required services. Age traditionally has been the starting point to determine how much longer the asset is anticipated to provide the required services. However, age does not always translate directly to actual asset performance. For example, assets may appear in poor condition and past their design life but are still performing required services. Conversely, newer assets early in their life cycle may be underperforming.

Performance is influenced by many factors, such as usage, operating environment, and maintenance interventions, and is directly related to probability of failure. Failure is defined as the inability of the system or asset to perform as required. As the asset performance degrades over time, the probability of failure increases. Information on prior failures coupled with other relevant factors (for example, historical condition) can help create a picture of performance over time or a specific deterioration/degradation rate. IAM (2016) SSG 31 lists five categories of factors from which performance information can be gathered:

- **Physical Condition:** Encompasses information from the inventory data (age, model, service date, warranties, etc.) and maintenance data (inspection, testing, preventive and corrective maintenance records, identified noncompliance, etc.).
- **Operating Condition:** Includes operational performance such as power surges, hours in operation, flow rates, overloads, trip counts, etc.
- **Operating Environment:** Incorporates information regarding the environment (weather conditions, humidity, traffic load, etc.).

- **Failure Rate:** Includes historical data on failures; ideally, this information would be coupled with problem root cause.
- **Critical Issues:** Incorporates other information relevant to performance (industry warnings, manufacturer recalls, obsolescence information, etc.).

Table 5-1 outlines several performance indicators and associated types of measures or assessments that can be used to identify or rate the level of impact of the performance factors listed above and help establish asset health, determine how well the asset is performing its required functions, and estimate how likely or for how much longer it will be able to continue to reliably perform those functions (probability of failure).

Table 5-1

Performance Indicators and Associated Types of Measures or Assessments (Applicability Varies by System Asset Type)

Indicator	Type of Measure
Visual condition	• Visual assessment • Nondestructive testing
Age/utilization	• Measure of consumed life/life remaining • Assessed relative to expected useful life or duty cycle
Obsolescence	• Are replacement parts available? Is asset maintainable? • Is asset supported by manufacturer?
Functional tests	• Onsite tests of asset functionality • Fluid, capacity, resistance, voltage, capacitance tests • Remote monitoring (e.g., SCADA, telemetry)
Asset performance	• Assessment based on maintenance records, trouble ticket counts, failures, in-service delays

These performance indicators can be numerically scaled or indexed into a framework to quantitatively and qualitatively rate asset health and help estimate the probability of failure. FTA's TERM Condition Rating Scale is an example of a performance framework used to qualitatively assess the visual condition of assets as an indicator of performance or likelihood of failure and assign a corresponding numerical rating.

Quantitatively, agencies could use available historical system performance data to calculate future probability of failure over time using statistical analysis applied to specific operating environments. In the absence of reliable historical data, the agency may use the opinion of experts in discrete performance areas. This approach would benefit from input from systems maintenance staff intimately familiar with the day-to-day operation of the system. (For a more in-depth description of this methodology, see IAM (2016) SSG 31.)

Rating scales and indexes can be developed to assess or measure all types of performance indicators and address factors specific to transit agency operating environment (for example, weather, usage, maintenance programs, and local safety and regulatory requirements). Table 5-2 shows the FTA TERM Rating Scale and additional example performance and obsolescence measure equivalents (that are not FTA official policy). Performance ratings are based on records for unscheduled maintenance (quantified by trouble ticket counts) as an example and range from very low to no trouble tickets (5) to levels where high trouble ticket numbers are considered unacceptable (1). Other trouble ticket-based performance measures may include maintenance hours, number of in-service failures, and duration of delay associated with in-service failures. The obsolescence scale ranges from ample and reliable vendor support (multiple qualified vendors) and parts availability (5) to no market activity or vendor support of the asset (1).

Table 5-2 *FTA TERM Rating Scale with Performance and Obsolescence Measure Equivalents*

Rating (FTA TERM Rating Scale)	Condition (FTA TERM Rating Scale)	Standard Definition (Visual Focus) (FTA TERM Rating Scale)	Performance Measure Equivalent (Not Official FTA Policy)	Obsolescence Measure Equivalent (Not Official FTA Policy)
5	Excellent	Like new, no visible defects	Very low to no trouble tickets/unscheduled maintenance	Not obsolete; 100% maintainable/ replaceable; high parts availability and compatibility; supported by multiple vendors; more than 5 years to end of life
4	Good	Some slightly deteriorated components	Low annual trouble tickets/unscheduled maintenance	Nearing end of product life cycle (2–5 years to end of life); 100% maintainable/replaceable; good parts availability; 1–2 vendors providing full support
3	Adequate	Moderately deteriorated components	Moderate annual trouble ticket counts/unscheduled maintenance	At end of life; still replaceable but declining parts availability; vendors/market provide limited support
2	Marginal	Deteriorated components in need of replacement	Higher/increasing annual trouble ticket counts/unscheduled maintenance	Obsolete non-critical item; past end of life; no replacement and low/no parts availability; technology no longer supported by market (for example, manufacturer no longer in business)
1	Poor	Seriously damaged components in need of immediate repair	Unacceptable/increasing annual trouble ticket counts/unscheduled maintenance	Obsolete critical item; past end of life; no replacement and low/no parts availability; technology no longer supported by market (for example, manufacturer no longer in business)

Obsolescence scale based on concepts of Product Life Cycle Model (EIA-724) and Diminishing Manufacturing Sources and Material Shortages.

Asset performance indicators, ratings, and indexes can become the basis for predicting future performance and probable failure date, which can be used as the foundation for planning maintenance (inspection, testing, preventive maintenance), renewals, and retirements. Table 5 3 presents examples of relevant life cycle management activities specific to transit systems in the utilization, support, and retirement stages that may be required to maintain, improve, or replace the system to sustain operations and system functions.

Table 5-3 *Example Transit System Activities During Utilization, Support, and Retirement Life Cycle Stages*

Lifecycle Stage	Generic Activities	Transit System Activities Examples
Utilization	Modify/improve	• Increase of throughput of electrified fixed guideway network - Signal system upgrades - Increased power generation/distribution • Enhancements to communications network to increase capacity and expand coverage • Increase of bandwidth in communications network of CCTV system to increase capacity and incorporate additional cameras • Change of software due to technology obsolescence • Incorporation of backup data centers for redundancy purposes • Addition of remote terminal units at new locations to expand SCADA system coverage • Renewal activities to extend the system's design life
Support	Monitor and maintain	• Regular inspection and rating • Performance monitoring and data gathering • Preventive maintenance • Corrective maintenance • Cybersecurity initiatives - Software upgrades and modifications - Installation of software security patches • Renewal activities to ensure meeting system design life while meeting original requirements - Upgrades to degraded or obsolete assets - Replacement of degraded or obsolete assets
Retirement	Replace with newer/upgraded version[a]	• Replacement of fixed block train control system with communications-based train control system • Replacement of fare collection system with new generation fare collection system • Replacement of older business applications with updated versions • Replacement of firewall devices and related software with latest generation devices and software

[a] *Implies that new or upgraded systems underwent the concept, development, and production stages (see Section 2.5).*

Maintenance activities are especially critical to preserving established system performance levels and managing the risk of failure. A good maintenance strategy is aimed at producing a predictable level of performance through the life cycle of the system. Commonly, systems manufacturers, suppliers and/or installers/integrators deliver to the system steward maintenance, inspection and/or testing schedules with recommendations for the frequency of implementation. These recommendations are generic and may need to be adjusted by system operators and maintainers to reflect unique local conditions and needs (IAM, 2015b). Unless system enhancements have been planned, programmed, and agreed upon by all responsible parties, renewal activities must be focused only on ensuring that the system original requirements are met. Changes to original system requirements that encompass enhancements and/or added new features may have huge implications for those operating and maintaining the system.

Maintenance activities can be categorized into three distinct groups as follows:

1) **Inspection, testing and monitoring:** These activities are aimed at evaluating and testing the performance of key subsystems or assets at predetermined time or cycle intervals. These activities may include visual

inspections, specialized testing, and remote condition monitoring (for example, use of special sensors to report real time performance data and to transmit the information to databases for storage).

2) **Preventive maintenance:** These are programmed maintenance activities established according to a schedule with the purpose of checking whether assets are performing at specified functional levels. This type of activity may encompass an evaluation of an asset and testing and/or replacement of components and subcomponents to ensure pre-determined performance levels.
3) **Corrective maintenance:** These activities are not planned and are direct result of system failure or degradation in levels of performance. The objective of these activities is to restore service within the preset levels of service (IAM, 2015b).

The recording of inspection, testing, and monitoring and maintenance activities can generate a wealth of critical data that can be used to assess the effectiveness of both preventive and corrective maintenance activities and to help plan future maintenance activities aimed at minimizing costs while maximizing results. This information can also be instrumental for planning medium to long-term capital renewals and replacements.

5.3 Performance Management Considerations and Methods by Systems Asset Class

This subsection presents example asset condition and performance monitoring methodologies, some currently in use at transit agencies, for each of the transit systems asset classes included in this handbook. Communications, Business Applications, and Tunnel Support asset class methodologies are very similar, as these systems operate similarly and are dependent on the same or parallel system networks and data centers. Table 5-4 provides a summary of example condition and performance metrics that may be used for transit systems asset classes.

Appendix F provides an illustrative (not all-encompassing) list of transit systems condition assessment methods, obsolescence, and performance monitoring options for select subsystems and system elements.

Table 5-4 *Transit System's Selected Condition and Performance Metrics*

Asset Class	Condition/Structural Assessment Metrics	Performance Metrics
Train Control and Signaling	• Spare parts availability • Fail-safe design • Percent of assets over design life	• Mean time to failure • System downtime • Number of control incidents • Inspections completed on time
Traction Power/ Electrification	• Spare parts availability • Fail-safe design • Average age • Percent of asset beyond design life	• Availability • Mean time between failures • Number of failure occurrences, including failures with no impact to train service
Communications and Control	• Spare parts availability • Fail-safe design • Average age • Obsolescence rate • Percent of asset beyond design life	• System failures • Reliability (down time or mean time between failure) • Design redundancy • Availability/uptime • Coverage • Capacity
Revenue Collection	• Time between failures • Reliability • Percent of assets beyond design life	• Availability of equipment for revenue service • Accuracy (fare calculation, accounting/ settlement) • Tag failures • Fares unaccounted for (lost transaction data) • Fare media validation
IT/Business Applications	• Obsolescence rate • Vendor support date	• User satisfaction • Average response rates • Error rates • Count of application instances • Request rate • Application and server CPU • Application availability • Processor usage • Memory use
Tunnel support	• Spare parts availability • Fail-safe design • Obsolescence rate • Percent of asset beyond design life	• Reliability (down time or mean time between failure) • Design redundancy • Availability • Coverage • Capacity

Source: FTA (2019c), Transit Asset Management Guide Supplement, *Chapter 5. Additional information for IT/Business Applications and Tunnel Support derived from various sources.*

5.3.1 Train Control and Signaling Systems

Train control and signaling systems are founded on safety and reliability features, and the cost of failure is high; consequently, the management and monitoring of these assets focus on managing risk. On the other hand, system performance is dependent on the interoperability of the various makes, models, and functionalities of subsystems and system elements. As another layer of complexity, as systems age and sustain extensive and continuous maintenance activities and upgrades, they develop a mix of older and new assets. This requires that replacement efforts prioritize interoperability, compatibility, and uniformity (FTA, 2016a).

There are multiple indicators or analogues that maintenance staff can use to assess the condition of traditional electromechanical signaling equipment. However, not all indicators are equally suited for condition assessment purposes. Indicators such as age or hours in operation are not useful analogs for the condition of most signal system assets (for example, relays, crossing gate mechanisms, switch machines) due to the significant variation of applications and operations. Some assets may see more or fewer activations or cycles depending on the frequency of rail service. Indicators such as tonnage, vehicle traffic (or scheduled trains), or number of cycles or activations are better analogs for asset condition because of their closer representation of actual use. These analogs can be used to develop a rating scale or index equating a condition rating to a maximum threshold or number range of cycles. The number of operation cycles is considered a strong indicator of condition for relays, switch machines, and grade-crossing gate mechanisms, as it represents equipment cycle activity over time. Manufacturers and industry research on asset reliability based on operation cycles can provide strong reference points for operators to plan their inspection, testing, and maintenance programs. Performance monitoring programs benefit most when local operating environment characteristics are considered.

Commuter rail operators that fall under FRA jurisdiction are required to follow the requirement of U.S. Code Part 236 that mandates specific test intervals (for example, vital vane and direct-current relays should be tested at least once every two years). Properties that do not fall under FRA jurisdiction may establish their inspection protocols, including frequencies and other technical recommendations based on manufacturer's and industry recommendations (FTA, 2019c). The American Railway Engineering and Maintenance-of-Way Association's *Communications and Signals Manual of Recommended Practices* (AREMA, 2018) includes automatic train control system testing recommendations.

Mobile inspection tools, such as electronic inspection forms and mobile apps on tablets and smart phones, allow inspection, testing, and maintenance data to be uploaded directly into a central database for processing. Field inspectors can record notes, expert assessments, and photographs or videos to enhance the effectiveness of these activities. State and local regulations must be consulted and adhered to as they vary on use of mobile inspection tools.

CBTC and PTC systems rely heavily on software and electronic equipment, which tends to have shorter life spans than electromechanical assets and are subject to technology obsolescence. In addition to train control regimes, the inspection, testing, and/or maintenance programs for these systems must conform to specific software and electric and electronics industry standards. Depending on the type of equipment in place, transit operators may need to adhere to Institute of Electrical and Electronics Engineers (IEEE) technical standards and recommendations for electronic equipment testing.

Train control systems are usually integrated with the agency's communications and SCADA systems. These systems can offer a variety of continuous performance monitoring options such as tracking failure rates and reliability scores. In addition, large data storage capacity can allow agencies keep historical performance data can be analyzed to identify higher risk subsystems and critical assets, especially those that are more likely to fail and cost more to fix or take longer to rehab/replace. These subsystems and assets can then be targeted for special preventive maintenance and upgrades. More advanced performance monitoring techniques can combine failure rates and reliability scores with additional information, such as hours in service, maintenance logs, vehicle miles, and temperatures, which can then be used as the basis for advanced reliability modeling (FTA, 2019c).

Transit operators could consider reviewing business cases that compare costs of proactive maintenance vs. reactive maintenance for different projects, this exercise can provide valuable insight for optimizing the timing of renewal actions and the assignment of maintenance personnel.

New technologies (many cloud-based) offer automated system monitoring of train control and signaling assets. The system operator can access real-time information, and historical data are stored in a database for data analysis. Some automated technologies have the capability to monitor multiple track section circuits in real time and to determine the health of track circuits by examining the current draw through the track relay. Switch machine monitoring technologies track the current draw when the switch is thrown; the resulting current waveform is a fingerprint that indicates the performance of both the switch machine and the turnout and can uncover developing problems before they occur. Some rail operators are already using high-resolution accelerometers[14] to track switch throws. Other technologies use mathematical models ("machine learning") to make predictions about the changes in a turnout's functionality, expected wear, and material defects to support predictive maintenance rather than repairs.

[14] An accelerometer is an electromechanical device used to measure acceleration forces. Such forces may be static, like the continuous force of gravity or, as is the case with many mobile devices, dynamic to sense movement or vibrations. Live Science.

When inspections or tests identify equipment failures (a switch, for example), staff can promptly perform renewal work (repairs or replacements). Often, the failure is not recorded, and only the end point of the inspection process and passing grade is recorded. To better understand overall system performance, agencies will benefit from having standards in place to uniformly capture both failures and corresponding renewal efforts.

5.3.2 Traction Power/Electrification Systems

Traction power electrification systems provide power for electric trolley bus, street car, light and heavy rail, and commuter rail operators. These systems are configured in one of two ways: overhead contact systems (OCS) or third rail systems. OCS incorporate a number of additional assets such as poles and tension wires and typically use underground duct banks commonly shared with utility companies. On the other hand, third rail systems more often have dedicated ductwork and total control of the right-of-way. Considering safety, these systems are commonly segmented into sections that can be electrically isolated to allow safe inspection, maintenance, and rehabilitation work (FTA, 2016a).

5.3.2.1 Inspection, Preventive, and Corrective Maintenance

Inspection and preventive maintenance activities center around third rail and OCS, which experience wear from vehicle traffic and are commonly exposed to the elements. Typically, traction power substations and cables are inspected at set intervals generating condition rates and data that, in turn, can be used to establish a preventive maintenance program aimed at keeping the traction power substations and all their equipment in good working order. Providing maintenance staff with mobile communications devices such as hand-held computers or tablets to support field maintenance work can be formidable tools to improve inspection and maintenance data collection processes, as they can eliminate the use of paper reports and files. Analysis of historical inspection and maintenance data collected can be used to determine the appropriate frequency and level of detail of inspection and testing routines as well as preventive maintenance program to meet the system specific needs.

When establishing the parameters for setting inspection, testing, and maintenance regimes that encompass scope and frequency, transit agencies generally use criteria that align with the following:

- Manufacturer recommendations
- Industry standards (for example, AREMA, IEEE, ASTM International, International Electrotechnical Commission)
- Agency overrides based on specific conditions (for example, environment, climate, terrain, local code)

A few examples of condition indicators and assessment methodologies for specific types and subcomponents of traction power systems (particularly commuter rail) are shown in Table 5-5.

Table 5-5

Example Traction Power Systems Asset Condition Indicators and Assessment Methodologies

Traction Power Asset	Example Condition Indicator or Assessment Methodology
Overall system (particularly older systems)	Obsolescence (accounts for risk of having a critical system asset fail with no replacement, which then requires replacement of all or a significant part of the system)
Transformer	Oil physical properties test (can use dissolved gas and acidity analysis or transformer cooling and insulating oil that provides an indirect evaluation of transformer condition)
Substation high-voltage switchgear, traction power transformer, DC rectifier, and DC switchgear	Manufacturer's design life adjusted for local conditions
Traction power cable system	Pass/fail criteria based on resistance measured by direct current (Megger) method (IEEE 400)
Electric traction motor generators	Manufacturer's design life adjusted for local conditions
Electric traction third rail	Number of trains (specifically, number of axles with contact shoes); measuring rail wear (by contour or position relative to running track) using a gauge

SCADA

Typically, traction power systems are supported by a SCADA system, which provides control, monitoring, and data storage capabilities. Accurate inspection, testing, and maintenance data recorded over time coupled with the massive amounts of performance data that a SCADA system collects can help system operators perform statistical analyses and allow them identify failure patterns. This information can also be used to create maintenance scenarios and the appropriate funding mechanisms (operating or capital) that will allow the timely procurement of necessary equipment and allocation of trained in-house staff or outsourced solutions. System diagnostics at the component level allow the operator to get an early warning of potential issues to allocate resources and can contribute to the reduction of failures.

Other Performance Monitoring Tools

New technologies with thermal imaging capabilities can scan impedance bonds and third rail for hot spots indicating high resistance connection, low resistance insulation (high leakage currents), and overloads of the traction power system. Similar equipment can scan transmission gear, switching equipment, and substation equipment to detect high resistance connections, overloads, and failing equipment. For use with OCS, cameras can record the exact location and specifics of instances where the pantograph loses contact with the contact wire. Additional optical technologies are being applied to OCS infrastructure to assess asset defects, wear, corrosion and degradation, geometry, and electrical properties. Also, advanced sensors can identify wear in the OCS that can then be addressed through special maintenance activities.

A U.S. rail operator has implemented limited helicopter inspections with ultra-high-resolution cameras that record images of critical traction power system elements along the right-of-way. This method has allowed the agency to inspect a significant number of assets in a shorter period and realize benefits by reducing the number service disruptions.

5.3.3 Communications and Control Systems

Modern communications systems are operated on IT platforms that use networks and specialized software to perform their functions. These systems also provide a wide array of control, monitoring, and data storage capabilities. These systems have certain features that determine how they are operated and maintained. Some salient characteristics of these systems with respect to performance monitoring include:

- Assets are dispersed throughout the operator's service area and may be difficult to access.
- Excluding network assets and data centers, most individual electronic assets are generally smaller in size and value (one camera costs less than $50,000), but in aggregate (total cameras owned) can far exceed the minimum cost threshold.
- Smaller electronic assets have shorter life spans (obsolete in less than 10–15 years) than electromechanical equipment and may be cheaper to replace than to maintain.
- The main drivers for replacing these types of assets are obsolescence and failures. Given the shorter life span of hardware and software communications systems, operators often are confronted with having to deal with obsolete assets. Software upgrades, increasing demand for data

bandwidth, and technology advancements also often drive replacement decisions of IT-based systems like communications and control systems. An older system may no longer be supported by the manufacturer, or obsolete software may not support modern hardware. These situations force system owners to weigh the decision of funding and procuring a new system or continuing to operate by finding and purchasing outdated replacement hardware or maintaining software development capabilities in house.

As for failures, the monitoring capabilities of communications and similar systems (for example, data acquisition software) decreases or altogether eliminates the need for maintenance or inspection programs for these types of assets. Instead, failed or underperforming equipment are identified, located, and replaced. However, some critical assets may require regular inspection, testing, and maintenance programs, such as preventive maintenance in line with manufacturer recommendations. Critical assets commonly belong to the network or to control, monitoring, and data storage. Communications system operators may want to consider implementing reliability engineering and reliability-centered maintenance programs for critical network assets such as programable logic units (PLCs), remote terminal units (RTUs), uninterrupted power supplies (UPSs), and backup battery sets. Tracking failure patterns (by type, location, etc.) and establishing reliability standards (for example, measuring performance through availability and setting a needed threshold of percentage of assets in service) can help identify performance issues specific to an asset model, deployment location, or other factors.

The Radio Communications Group of a U.S. transit operator use a special software to help them continuously monitor radio system performance. To ensure business reliability and business continuity they incorporate additional:

- *Coverage tests*
- *Drive tests to measure signal strength*
- *Annual inspections of equipment*

The group maintains a warehouse with spares to support maintenance functions. In addition, they coordinate with the budget office regarding immediate, medium, and long-term needs. The group also maintains radio antennas. Each antenna is assessed for:

- *Transmission power*
- *Reception sensitivity*
- *Functionality*

In addition to the communications, control, and security system life cycle management considerations presented in the *TAM Guide Supplement* (FTA, 2019c) (such as shared systems and interagency agreements, vendor (or cloud) services, and system design implications), there are several areas of potential risk related to performance and management of the system if not addressed, including cybersecurity, implementation of redundant networks, and system equipment housings/rooms.

5.3.3.1 Cybersecurity

Vital operations and business information is continuously sent and received via a transit agency's communications networks, requiring a cybersecurity program that protects the integrity of the information being transferred. A cybersecurity program starts with a security management framework of security policies that meet the operator's network requirements. The program must ensure that all network devices are configured to the same security level while continuously scanning the security status of devices and monitoring when new devices are added to the network. The program should include an event log capable of comparing network configurations before and after incidents. Key security features may include the ability to segment large-scale networks into smaller networks to decrease the chances that one incident will affect the entire network. To ensure data integrity, the network can secure a tunnel for encrypted data transmission and systematically deploy firewall devices in the most cost-effective manner. At the device level, the system will be able to identify and control who can log in to devices, verify authorized devices before they gain access to the network, communicate with other devices, and encrypt data transfers to ensure data integrity and confidentiality.

5.3.3.2 Redundancy

Communications networks are vital to several safety-sensitive systems such as train control (CBTC and/or PTC), CCTV, access control and intrusion detection, tunnel ventilation, and fire/smoke detection and suppression. This warrants the need for building or having access to redundant networks that can allow the system to continue its operation in case of a network outage.

Data centers host the servers that contain the software and business applications that allow systems to operate. Similarly, backup data centers are placed in operation to swiftly cover for any data center service disruption. The exact same concept is applied to transit operations control centers. To cover for any disruption of control and monitoring capabilities, redundant operations control centers are built at alternative locations to allow transit operators to continue to operate without disruption when the main operations control center undergoes maintenance and service upgrades or experiences some other type of service disruption.

5.3.4 Revenue Collection Systems

Revenue collection systems interface directly with transit users and sustain heavy use. Failure of subsystems or system elements, whether physical assets (for example, fareboxes, faregates, automatic vending machines, and fare validators) or software, directly impacts the system revenue stream and can affect the delivery of service by slowing customer access to the system. The criticality of the system warrants robust response procedures for outages to minimize downtime. Agencies can set targets for equipment availability (by equipment type, mode, division, facility, etc.) and develop maintenance plans to achieve those targets.

Although vending machines, fareboxes, and faregates are designed to endure heavy use, fare collection system managers would benefit from having defined preventive and corrective maintenance programs and protocols in place. Maintenance teams must take into consideration the challenges of having their assets disseminated over an extended territory (for example, larger commuter rail operators commonly cover territories that span hundreds of miles). Maintenance work can be determined based on the number of transactions or actions by the machines, so that machines experiencing more transactions over a period receive heavier maintenance. As with any electromechanical type of equipment, it is expected that maintenance needs of equipment will increase over the life cycle of the asset.

Electronic fare collection system failures are often caused by software failures. Unlike failures of individual electromechanical assets, such as automatic vending machines or faregates, failures in software can have a more detrimental impact on the system reliability and potentially halt the entire revenue collection operation. Transit agencies must ensure that vendors are accountable for performance and provide low-risk software support (for example, through a fixed maintenance support fee rather than through charges for individual trouble tickets or work orders).

Since revenue collection systems run on information technology platforms with data acquisition capabilities (similar to those of a SCADA system), they can track equipment performance in real time. The type of information that these systems provide can be extremely detailed. For example, a system can identify and track the performance of an individual circuit board in a fare vending machine. In addition to real time tracking, these systems can be linked to databases that store enormous amounts of historical data.

5.3.4.1 Vendor vs. In-House Services

Like other communications and information technology-based systems, the operation of a revenue collection system can be managed entirely by a third party. Under this type of arrangement, the vendor manages the system for a fee and is responsible for the delivery of an agreed-upon level of service, managing both software and equipment. This type of arrangement might include the scheduling of preventive maintenance activities by the vendor with constant monitoring of remedial or reactive maintenance calls. Typically, under this type of agreement, transit agencies have direct access to real time and historical data to help them track the system performance and vendor response times to issues.

Alternatively, agencies can maintain complete charge of operating and maintaining their revenue collection system, some internally developing custom fare collection system software. Full management responsibility and in-house software development capabilities allows changes to the system (software) business rules to be made with relative ease. Transit agencies can also obtain and use network services to connect the system as well as data storage from cloud-computing service providers. When the management and maintenance of the system is managed internally, there is need for increasing levels of coordination as not all system elements may be within the jurisdiction of the revenue collection team.

Although technically similar, revenue collection systems often are organizationally separated from communications and IT systems, except for the connecting network that is often managed by a communications or IT department.

5.3.5 Information Technology (Business Applications)

Because the core service provided by business applications comes from the software, it is most often the software and its associated risk of technological and vendor obsolescence that drives system-level performance and replacement decisions. As with communications systems, obsolescence and failures are the two key indicators of IT system performance and viability as to whether it fulfills its required functions. Table 5-6 outlines drivers for software replacement as identified by four different transit agencies.

Table 5-6

Drivers for Software Replacement

Agency A	Agency B	Agency C	Agency D
• Replace software if more than two generations old • End of vendor support • Never behind two quarter cycles of security patches	• Cybersecurity concerns • End of vendor support • Warranties	• End of vendor support • End of security patches • Replace software once new version released	• End of vendor support • Security risk • Replace software once new version released

Although there are numerous functional tests used within the field of software engineering to test software performance and risk of failure under a particular load, they are likely to be less illuminating for transit agencies than focusing on the usability, utility, and functionalities of the software in support of day to day transit operations. As with the drivers in Table 5-5, consider the following criteria when evaluating the performance of business applications:

- Does it meet business or operational needs?
- Is vendor or in-house software development support readily accessible to manage issues or failures?
- Is the software compatible with other dependent business applications used by the agency?
- Does the software support new/upgraded hardware? If not, is spare legacy hardware available in the event of failures?
- Is the software responsive and reliable while in use?
- What are typical levels of user satisfaction?
- If the software fails or underperforms, are there critical dependent systems that will be unable to perform required functions?

To help determine the viability of IT systems (business applications), a major U.S. transit operator asks the following questions:

- *Does it comply with regulatory requirements?*
- *Does it meet business needs?*
- *How is it performing with respect to the "total cost of ownership"?*

As discussed in Section 4, software associated renewal costs, such as licenses, subscriptions to cloud services, security patches, and upgrades, can represent significant investments in the operation of IT business applications and must be evaluated in the context of the software performance. Another key cost impact is the level of customization of the software. Agencies must weigh the benefits of having specialty software customized to meet unique and specific needs with the extra costs and specialization required to procure, maintain, and support highly-customized software.

As a rule of thumb, a major U.S. transit operator budgets 20 percent of software acquisition costs to support future upgrades and maintenance costs.

Although IT systems are centered around the software, the other subsystems and system elements (hardware, network, data center) can be impacted by software changes. Data servers must be upgraded in parallel with the evolution of software. The data network and hardware should also be reviewed for requirements and benefits of modernization at the time of new software introduction.

5.3.6 Tunnel Support

Traction power systems of large rail operators commonly deliver power to other systems, such as train control and signaling, tunnel ventilation and fire detection/prevention systems, tunnel, station and facility lighting, and water pumps. Tunnel ventilation and lighting systems commonly fall under the maintenance responsibility of traction power/electrification and/or facilities maintenance departments. Tunnel ventilation systems are commonly served with regular inspection regimes (monthly or quarterly) and complementary preventive maintenance programs. SCADA or other similar systems allow operators to monitor tunnel ventilation and fire prevention/suppression systems performance in real time. Historical performance data of critical system elements is or can be used by maintenance personnel to plan future inspection and maintenance programs.

5.4 Investment Prioritization

Transit systems are constantly monitored for performance and undergo regular inspection, maintenance, and corrective activities when warranted, often under operating budgets. However, when agencies are confronted with the need to make major capital investments to maintain, modify, or expand the system's level of service, or to altogether replace it with a new system, agencies are confronted with several constraints that typically include tight budgets, staff availability, technical complexities, contractual arrangements, project deliverability[15] and legal requirements. In this environment, these new system projects compete with other projects within the agency. A capital investment prioritization process weighs the importance of different criteria, such as funding availability, risk, safety, or compliance, to determine where and when to allocate resources.

5.4.1 Introduction to Risk-Based Decision-making

A risk-based selection process can support decision-makers in determining the most appropriate use of available resources (people and money) as well as the timing for implementation. This section provides a high-level description of a risk-based selection process framework. A risk-based approach incorporates information based on a system's maintenance activities and testing. Quality maintenance and testing data are instrumental in supporting these efforts, allowing for a data-driven approach. It can be difficult to track costs of all maintenance efforts as staff often quickly fix issues to prevent systems from failing, putting in hours of work that are not necessarily recorded. Each agency must evaluate the best way to record these activities to better plan and decide on maintenance for systems. In addition, the process will benefit from

[15] This entails constraints with regards to accessing the worksite. For example, renewal activities along the right-of-way for a subway traction power system that cannot stop regular operations reduces the time window for completing the work while increasing the project level of complexity.

the opinions of expert system maintenance personnel, which may be able to supplement areas lacking quality data.

Addressing risk is the foundation of decision making in operations and maintenance (O&M) or capital investment strategies. Evaluating risk takes into consideration two basic dimensions: probability of failure and consequence of failure. Probability of failure is associated with system or asset performance, condition, or health, whereas consequence of failure relates to criticality, or the importance of the system or asset to the operation or function.

$$\textit{Risk} = \textit{Probability of failure} \times \textit{Consequence of failure} \approx \textit{Health} \times \textit{Criticality}$$

Consequence and criticality represent the intensity or severity of business or performance impact once a system or its associated assets fail. As in the case of probability of failure, there are several approaches to determining consequence of failure, or criticality of the system or asset. (Information on different methodologies used can be found in IAM [2016] SSG 31.) There is consensus among industries on business or performance impact areas or types of consequences which can be adjusted or customized to meet the agency's goals and objectives. The following are well-known impact areas that are applicable to the transit industry:

- **Service:** Impact on customers in not being able to offer the expected level of service. In the transit environment, the transit operator might want to assess the number of riding customers affected by a non-performance of a system (for example, the impact of interruption of service due to a failure of service on a transit operator could be measured by the number of riders affected).
- **Health and Safety:** Harm to people (for example, the public, passengers, or agency staff).
- **Environmental:** Harm to the physical environment.
- **Financial:** Costs related to reduced levels of service or interruption of service (for example, disruptions due to a failed signal system might have several cost impacts, including repair costs, lost productivity costs, and decrease in fare revenue).
- **Stakeholder or Reputation:** Impact that degraded levels of service have with riding customers and also with funding or financing entities. It is important to note that a poor reputation might negatively impact agencies seeking to issue or refinance debt to help fund their operations and/or capital programs. A poor level of service may negatively impact the credit rating of a transit agency, which will result in higher costs to borrowing money.

Just as system performance and probability of failure can be scaled or indexed (see Section 5.1), criticality and consequence of failure can be banded to a rating scale. Table 5-7 displays an example generic criticality index split into four impact levels, from low to very high.

Table 5-7

Example of a Criticality Index

Level	State	Description
CI-1	Low	No material consequences from a failure or restricted to a minimum.
CI-2	Medium	Consequences of failure are well within acceptable or tolerable limits.
CI-3	High	Consequences of a failure are near limit of acceptability or tolerability' performance of these assets requires ongoing monitoring.
CI-4	Very High	Consequences of failure are unacceptable or above agreed tolerable limits. When combined with high Health Index values, corrective action required, as risk is not acceptable to the business.

Source: IAM (2016) SSG 31

With probability of failure (performance, condition, or health scales or indexes) and consequence of failure (criticality index) ranges in place and divided into bands, they can be merged to form a risk matrix. Table 5-8 depicts an example risk matrix that combines probability or likelihood (y axis) and consequence or impact (x axis) values divided into five bands each. Probability of failure has been divided into bands ranging from unlikely to frequent or almost certain. Consequence of failure has been divided into bands ranging from insignificant to catastrophic. This 25-cell risk matrix shows that a low probability of failure and low consequence of failure will result in low risk (R1 cells in lower left area). Next in the scale is moderate risk slightly to the right on the impact scale and slightly above the probability scale (R2 cells to the left and below of the midrange area). A higher risk area continues to the far right of the impact scale and to the top of the probability scale (R3 cells to the right and above in the midrange area). The highest probability and highest consequence combined will result in extremely high risk (R4 cells in the upper right corner).

Table 5-8 *Example of a Risk Matrix (No.1)*

Probability (Likelihood)	Insignificant Consequence (Impact)	Minor Consequence (Impact)	Moderate Consequence (Impact)	Major Consequence (Impact)	Catastrophic Consequence (Impact)
Frequent or Almost Certain	R3	R3	R4	R4	R4
Likely	R2	R3	R3	R4	R4
Occasional or Moderate	R1	R2	R3	R4	R4
Seldom	R1	R1	R2	R3	R4
Unlikely	R1	R1	R2	R3	R3

R1 = Low Risk, R2 = Moderate Risk, R3 = High Risk, R4 = Extremely High Risk
Source: FTA (2016a)

Table 5-9 depicts an alternate risk matrix where the probability range has been divided into five bands (Health Indexes, in columns 1–5), and the consequence range has been divided into four bands (Criticality Indexes, in rows 1–4).

Table 5-9 *Example of a Risk Matrix (No. 2)*

		HI 1	HI 2	HI 3	HI 4	HI 5
CI 1	Low criticality	RI 1	RI 1	RI 1	RI 2	RI 3
CI 2	Medium criticality	RI 1	RI 1	RI 2	RI 2	RI 3
CI 3	High criticality	RI 1	RI 1	RI 2	RI 3	RI 4
CI 4	Very high criticality	RI 1	RI 1	RI 2	RI 4	RI 5

RI 1 = Lowest Risk, RI 2 = Lower Risk, RI 3 = Medium Risk, RI 4 = Higher Risk, RI 5 = Highest Risk
Source: IAM (2016) SSG 31

At one U.S. transit property, the maintenance and engineering teams partner to link the agency's maintenance records to its risk register, which gets reviewed annually. To establish criticality, the agency looks at the following criteria:

1) *Does it have redundancy?*
2) *What does it affect?*
3) *When it fails, how long is it down?*
   – *Is there a plan for replacement?*
   – *What is the plan for failure today?*
   – *If no plan for replacement, what should it be?*

5.4.2 Transit Systems Prioritization Process Development

The risk-based prioritization process can benefit from routine inspection, testing, and monitoring information coupled with data from preventive and corrective maintenance actions. The historical information gathered can then be used to create probability of failure and consequence of failure scales and to establish the impact of a system element failure on the overall operation of the system. With these probability and consequence scales in place, system elements can be placed in a risk-based matrix to help prioritize short to medium term maintenance actions and medium to long term renewal or replacement actions.

The following are building blocks to help establish a generic framework for risk-based investment prioritization to ensure system operational reliability:

- Basic requirements
  – Ensure asset inventory completeness
  – Ensure data quality
  – Ensure data quality continuity

  - Maintain records of relevant inspection, testing, monitoring, and maintenance data
- System specific requirements
  - Extract systems asset inventory
  - Identify key operational subsystems and system elements (this exercise is not meant for every system element)
  - Develop probability of failure (asset performance, condition, health) scale using inspection, testing, and maintenance data (or expert opinion where quality data are lacking)
  - Develop a consequence of failure (asset criticality) scale using criteria such as the following:
    - Service
    - Health and safety
    - Environmental
    - Financial
    - Stakeholder or reputation
    - Interoperability of subsystems and system elements
  - Build a risk matrix from the probability and consequence scales
  - Use risk matrix to help prioritize investments

The following main drivers (listed in order of importance) are used by some transit operators to prioritize investments for train control and communications systems:

1) *Asset performance*
2) *Obsolescence*
3) *Increasing maintenance costs*
4) *New technologies*
5) *Age*

5.5 References

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Section 6

National Transit Database Asset Inventory Module Systems Reporting

6 National Transit Database Asset Inventory Module Systems Reporting

Under the National Transit Database (NTD) program, FTA collects financial, operating, and asset information from transit providers on which to base public transportation service planning. AIM is a subset of the NTD program and currently includes requirements pertaining to two system asset classes included herein—traction power and train control/signal systems (summarized in Table 6-1). The annual *NTD Policy Manual* outlines specific reporting requirements. This section is intended to provide an overview of and supplemental guidance on NTD reporting specific to traction power and train control but the *NTD Policy Manual* remains the document of authority on reporting requirements and supersedes any discrepancies herein.

Table 6-1 *NTD Requirements for System Assets under Form A-20*

System Asset Class	System Elements	Required to Report Quantity?	Required to Report Whether They Have These Assets?	Required to Report Age Group by Quantity or Percentage?
Traction Power	Substation building	Yes	Yes	Yes
	Substation equipment	No	Yes	Yes
	Third rail/power distribution	No	Yes	Yes
	Overhead contact system/ power distribution	No	Yes	Yes
Train Control and Signaling	Train control and signaling	No	Yes	Yes

6.1 Substation Building Reporting

Substation buildings and equipment are reported as part of the NTD AIM on Form A-20; they are not reported as facilities on Form A-15.

As discussed in Section 3, substations can be standalone buildings or part of a larger facility. If the substation equipment housing is considered more permanent (for example, structural walls and roof as opposed to open-air chain-link fencing), agencies may find it beneficial to assess the condition of the enclosure according to FTA's facility condition assessment guidelines even though this information is not required for reporting purposes.

Substation buildings are the only power system element for which agencies must report a quantity. When counting substations, agencies should think of one single substation as the building(s), shell(s), or parts of facilities that contain the working elements or subcomponents of one substation operation. There may be multiple buildings or enclosures that house different equipment supporting the substation. For example, a location may have substation control equipment in one building, with transformers and other equipment in an adjacent enclosure. The two structures would be counted as one substation in the NTD AIM.

6.2 Reporting for Nontraditional Rail Transit Modes

If an agency operates inclined plane or cable car modes, associated motors and cables should be reported under the substation equipment system element.

6.3 Key Considerations for Translating Asset Inventories into the NTD AIM Form A-20

The five traction power and train control/signaling system elements listed in Table 6-1 must each be reported on Form A-20 in aggregate by mode. These system guideway elements should not be split or further broken down by any criteria other than mode for NTD reporting; if a system element is shared between modes, it should be counted only once and in association with the primary mode.

Figure 6-1 illustrates example information entered in the first few columns of Form A-20 (see Form A-20 to view all columns and required fields.) The first three rows of example data in Figure 6-1 are substation building line items for three different modes of service—commuter rail (CR), heavy rail (HR), and light rail (LR) (mode entered in Column A). Substation buildings are the only traction power and train control guideway elements that require a quantity or “Count” (column E) to be entered, which is why the other cells in the “Count” column that pertain to non-substation building guideway elements are grayed out.

Figure 6-1

Example Entries for Power and Signal System Elements on Form A-20

	A	B	C	D	E	F	G
2	Mode	Service	Guideway Elements	N/A	Count	Linear Miles	Track
3	CR	DO	10. Substation Building		75		
4	HR	DO	10. Substation Building		30		
5	LR	DO	10. Substation Building		15		
6	CR	DO	11. Substation Equipment				
7	HR	DO	11. Substation Equipment				
8	LR	DO	11. Substation Equipment				
9	HR	DO	12. Third Rail/Power Distribution				
10	CR	DO	13. Overhead Contact System/Power Distribution				
11	LR	DO	13. Overhead Contact System/Power Distribution				
12	CR	DO	14. Train Control & Signaling				
13	HR	DO	14. Train Control & Signaling				
14	LR	DO	14. Train Control & Signaling				
15							
16							

Age information is also required for the five traction power and train control/ signaling system elements (see Form A-20 for all required fields). Figure 6-2 illustrates example age group entries for the system elements listed on Figure 6-1. (Note that some columns have been hidden on Figure 6-2 for viewing purposes.) Each system element or row on Figure 6-2 represents an aggregate of all associated assets and their ages. For example, the CR substation building line item (row 3) is an aggregate representation of all substation buildings that support commuter rail service for an agency. The age distribution of these aggregated assets can be entered by quantity of assets or by percentage of assets.

	A	C	M	Q	R	S	T	U	V	W
2	Mode	Guideway Elements	Allocation Unit	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019
3	CR	10. Substation Building	Quantity				5	40	7	23
4	HR	10. Substation Building	Quantity					25		5
5	LR	10. Substation Building	Quantity					2	10	3
6	CR	11. Substation Equipment	%			3	6	28	36	27
7	HR	11. Substation Equipment	%					83		17
8	LR	11. Substation Equipment	%					13	67	20
9	HR	12. Third Rail/Power Distribution	%			3	48	14	17	18
10	CR	13. Overhead Contact System/Power Distribution	%				44	12	17	27
11	LR	13. Overhead Contact System/Power Distribution	%					50	50	
12	CR	14. Train Control & Signaling	%							100
13	HR	14. Train Control & Signaling	%	2	4	13	16	37	13	15
14	LR	14. Train Control & Signaling	%		6	10	15	39	15	15
15										
16										

Figure 6-2 *Example Age Group Entries for Power and Signal System Elements on Form A-20*

Current NTD AIM reporting does not allow for individual system element assets (for example, a line item for each substation building owned and operated by the agency) to be submitted to FTA. However, agencies will need an inventory of individual assets and their ages to accurately group the system assets by age for reporting on Form A-20.

Age is determined by the date of completed construction or date of installation. Renovations or rehabilitation work are considered a normal part of the cost of asset ownership and do not necessarily impact the age of the facility. If an agency wishes to refine the asset age, there are many methods that can be used. Different ages can be assigned to different percentages of the asset based on cost. For example, a substation building built 30 years ago but had the roof replaced two years ago could have an age of two years assigned to a percentage that corresponds to the cost of the roof as a percentage of the total substation cost (for example, 30%). The remaining percentage (70%) would have an assigned age of 30 years. The overall substation building age would then be a weighted average of the ages (21.6 years). Another alternative is to assign the age of a renovated or rehabilitated asset based on the age of the highest cost component.

The age of each individual asset must then be aggregated to determine the age distribution of the corresponding system guideway element (for example, substation equipment, train control and signaling) that is then reported on

Form A-20. Figure 6-3 helps to illustrate how this aggregation can occur (certain columns have been hidden for viewing purposes). Figure 6-3 presents example age data for the group of individual substation equipment assets that were aggregated to determine the age distribution entries for the commuter rail substation equipment guideway element line item in row 6 of Figure 6-2. In practice, agency's asset inventories may include thousands of assets instead of the 16 items listed on Figure 6-3, which is intended to serve as an abbreviated example.

	A	C	K	M	S	T	U	V	W
2	Mode	Guideway Elements	Other Description	Allocation Unit	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019
3	CR	11. Substation Equipment	DC Switchgear A1	%				100	
4	CR	11. Substation Equipment	DC Switchgear B1	%			100		
5	CR	11. Substation Equipment	DC Rectifier A1	%				100	
6	CR	11. Substation Equipment	DC Rectifier B1	%					100
7	CR	11. Substation Equipment	Transformer A1 - 480V	%			100		
8	CR	11. Substation Equipment	Transformer A2 - 480V	%			100		
9	CR	11. Substation Equipment	Transformer B1 - 480V	%				100	
10	CR	11. Substation Equipment	Transformer B2 - 480V	%					100
11	CR	11. Substation Equipment	Transformer C1	%				100	
12	CR	11. Substation Equipment	Transformer C2	%					100
13	CR	11. Substation Equipment	Transformer C3	%					100
14	CR	11. Substation Equipment	Battery System A1	%				75	25
15	CR	11. Substation Equipment	Battery System B1	%			50	50	
16	CR	11. Substation Equipment	Battery System C1	%		100			
17	CR	11. Substation Equipment	AC Switchgear D1	%	50			50	
18	CR	11. Substation Equipment	AC Switchgear E1	%			100		

Figure 6-3 *Example Asset Inventory Entries for Substation Equipment System Element in NTD AIM Format*

A "percentage of percentages" can be calculated to determine the aggregated age distribution. In this example, 50 percent of the AC Switchgear D1 equipment in row 17 on Figure 6-3 dates to the 1970s, the only entry in that age group for all 16 of the substation equipment assets listed on Figure 6-3; 50 percent of the AC Switchgear D1 equipment translates into 3.125 percent of the total substation equipment (the 16 items). By rounding to the nearest whole number, 3 percent is then recorded in the 1970s column in row 6 on Figure 6-2 for the aggregated commuter rail substation equipment guideway element line item.

Individual assets with age allocations split between multiple age groups can indicate partial renovations, replacements, or incremental installations. The example substation equipment entries on Figure 6-3 include both subsystems and sub-assets, so an even more detailed breakdown may have been required to determine these age distributions. For example, the age distributions of the battery systems in rows 14–16 may be based on an aggregation of even lower level components (battery, battery charger, cables, etc.). The hierarchies and level of detail will depend on the business requirements of the agency's asset management program.

6.4 TAM System Asset Classes Not Required under 2019 NTD AIM

Reporting requirements in the 2019 NTD AIM do not include the Communications, Fare Collection, Business Applications, and Utility systems asset classes discussed in this handbook. Table 6-2 shows the system asset classes included in this handbook with a few system type examples and differentiates those that are required to be reported under the current NTD AIM from those that are not.

Table 6-2 *Transit Systems Asset Classes and NTD AIM Requirements*

Asset Classes	2019 NTD AIM Requirement	System Types/Elements Examples
Vehicle Control and Signaling	Yes, except for TSP	• Fixed block train control • CBTC • PTC • TSP[a]
Traction Power	Yes	• Third rail • Overhead contact system
Communications	No	• CCTV • PA • Radio • Telephone • CAD/AVL • SCADA
Revenue Collection	No	• Revenue collection equipment • Electronic fare collection • Web-based fare collection
IT/Business Applications	No	• Enterprise asset management and maintenance management systems • HR and payroll • Crew assignment • Budgeting and financing • Capital maintenance system • Procurement
Tunnel Support	No	• Tunnel ventilation system
Enabling Systems –– Networks[b]	No	• Cabling (fiber-optics, copper, Ethernet, and others) • Wireless communication • Linkage and security hardware
Enabling Systems – Control, Monitoring and Data Storage[b]	No	• Data centers • Systems control, monitoring and data storage hardware and software

[a] *NTD AIM includes train control systems but does not include transit signal priority systems.*

[b] *Enabling systems allow other systems to operate by providing critical linkage, control, monitoring, and data storage functions.*

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Section 7

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7 References

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APPENDIX

A

Abbreviations and Acronyms

AC	alternating current
ACRP	Airport Cooperative Research Program
ACS	Asset Class Strategy
ADK	Windows Assessment and Deployment Kit
AIM	Asset Inventory Module
ANSI	American National Standards Institute
APTA	American Public Transportation Association
AREMA	American Railway Engineering and Maintenance-of-Way Association
ATC	automatic train control
ATO	automatic train operation
ATP	automatic train protection
ATS	automatic train supervision
AVL	automatic vehicle location
AVPS	audio visual paging system
BART	Bay Area Rapid Transit
BAS	building automation system
BESS	Battery Electric Storage System
BMS	building management system
C&P	conditions and performance
CAD	computer-aided dispatch
CBTC	communications-based train control
CCTV	closed-circuit television
CR	commuter rail
CTA	Chicago Transit Authority
DAS	distributed antenna system
DC	direct current
DCS	distributed control system
DOO	driver-only operation
DVR	data video recorder
EAM	enterprise management system

EIA	Electronic Industries Alliance
ERTMS	European Rail Traffic Management System
ESS	electronic switching system
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GPS	global positioning system
HMI	human-machine interface
HR	heavy rail
I/O	input/output
IAM	Institute of Asset Management
IDF	intermediate distribution frame
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INCOSE	International Council on Systems Engineering
IoT	Internet of Things
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISO	International Organization for Standardization
IT	information technology
KPI	key performance indicator
LFEPA	London Fire and Emergency Planning Authority
LiDAR	Light Detection and Ranging
LMR	land mobile radio
LR	light rail
M2M	machine-to-machine
MAP-21	Moving Ahead for Progress in the 21st Century Act
MDT	Microsoft Deployment Toolkit
MMS	maintenance management system
NASA	National Aeronautics and Space Administration
NTD	National Transit Database
NVR	network video recorder
O&M	operations and maintenance
OCS	overhead contact system

PA	public address
PAS-55	Publicly Available Specification 55 (from the British Standards Institute)
PBX	private branch exchange
PC	personal computer
PCR	public cellular radio
PLC	programmable logic controller
PMR	public mobile radio
PoE	Power over Ethernet
PSU	power supply unit
PTC	positive train control
RTU	remote terminal unit
SAMP	strategic asset management plan
SCADA	supervisory control and data acquisition
SEPTA	Southeastern Pennsylvania Transportation Authority
SSG	subject-specific guidance
TAM	transit asset management
TBP	Federal Transit Administration Office of Budget and Policy
TERM	Transit Economic Requirements Model
TPE	Federal Transit Administration Office of Planning and Environment
TPM	Federal Transit Administration Office of Program Management
TPSS	traction power substation
TSP	transit signal priority
UPS	uninterrupted power supply
VMS	variable message sign
VoIP	Voice over Internet Protocol
WPA	wi-fi protected access

APPENDIX

B

Glossary

This handbook incorporates concepts and terminology that are included in the FTA Transit Asset Management (TAM) Guide and the Terms and Definitions sections of various publications by the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), the Institute of Electrical and Electronics Engineers (IEEE) and the International Council on Systems Engineering (INCOSE). These terms provide the basis for asset management and transit systems vocabulary and understanding aimed at establishing common language applicable to the transit industry.

Key Asset Management Concepts

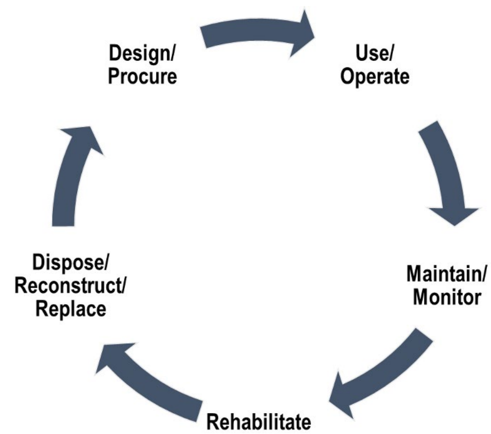
Asset Management Business Plan: A document that outlines the implementing activities, roles, responsibilities, resources, and timelines needed to address an agency's asset management policy and strategy. More information on developing an asset management business plan is in Section 3 and Section 5.

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

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

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

Life Cycle Management: Enables agencies to make better investment decisions across the life cycle using management processes and data specific to each asset as a basis for predicting remaining useful life (including age, condition, historical performance, and level of usage). Transit asset management involves processes for managing and maximizing the performance of an asset while minimizing its costs throughout the course of its life cycle. Life cycle activities are shown on the figure.



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

Plan can be used to ensure that the performance expectations of the asset are understood and fit within the agency's broader goals and performance objectives and that all investment decisions are transparent and well-communicated.

- **Transit Asset Management:** 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 life cycle to provide safe, cost-effective, reliable service to current and future customers.

Other Terminology

Acquisition: Process of obtaining a system, product, or service (ISO 15288).

Activity: A set of cohesive tasks of a process (INCOSE, 2015).

Application Software: Computer program that performs a set of functions to support the execution of a process (ISO/TC 22163). *Note:* Can be a software program, database, computerized spreadsheet, electronic file, or web tool bought from the market or developed by the organization.

Architecture: Fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution (ISO 15288).

Asset Category: A grouping of asset classes, including a grouping of equipment, of rolling stock, of infrastructure, and of facilities.

Asset Class: A subgroup of capital assets within an asset category. For example, buses, trolleys, and cutaway vans are all asset classes within the rolling stock asset category.

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

Asset Hierarchy: The system organization of an asset group that shows the relationship ("parent-child") between the highest level of the asset down to its different components.

Asset Management Business Processes: The six key processes that comprise the transit asset management framework. Business processes include, for example, asset management policy, capital planning and programming, and condition assessment and performance monitoring.

Asset Management Framework: Provides a structure that outlines best practice in asset management practice; comprises six business processes, including, for example, asset management policy, capital planning and programming, and condition assessment and performance monitoring.

Asset Management Program Manager: Person held accountable for development, maintenance, and implementation of the asset management business plan. Also responsible for communicating with the executive team, leading the enterprise asset management team, and managing internal and external communications regarding the asset management initiative.

Asset Management System: Management system for asset management whose function is to establish the asset management policy and asset management objectives (ISO 55000). *Note:* The asset management system is a subset of asset management.

Asset Management Strategy (also see Strategic Asset Management Plan): Long-term optimized approach to management of assets, derived from and consistent with the organizational strategic plan and the asset management policy (Publicly Available Specification 55-1). *Note:* An asset management strategy converts the objectives of the organizational strategic plan and the asset management policy into a high-level, long-term action plan for the assets and/or asset system(s), the asset portfolios, and/or the asset management system. High-level, long-term action plans for the assets and the asset management objectives are normally the outputs of the asset management strategy. These elements together from the basis for developing more specific and detailed asset management plan(s).

Asset System: Set of assets that interact or are interrelated (ISO 55000).

Attribute: Characteristic of an object or entity (ISO 2382-36).

Audit: Independent examination of a work product or set of work products to asses compliance with specifications, standards, contractual agreements, or other criteria (ISO 15288).

Automatic Train Control (ATC): The system for automatically controlling train movement, enforcing train safety, and directing train operations. ATC must include automatic train protection and may include automatic train operation and/or automatic train supervision (IEEE Standard 1474.1).

Automatic Train Operation (ATO): The subsystem within the ATC system that performs any or all of the functions of speed regulation, programmed stopping, door control, performance level regulation, or other functions otherwise assigned to the train operator (IEEE Standard 1474.1).

Automatic Train Protection (ATP): The subsystem within the ATC system that maintains fail-safe protection against collisions, excessive speed, and other hazardous conditions through a combination of train detection, train separation, and interlocking (IEEE Standard 1474.1).

Automatic Train Supervision (ATS): The subsystem within the ATC system that monitors trains, adjusts the performance of individual trains to maintain schedules, and provides data to adjust service to minimize inconveniences otherwise caused by irregularities (IEEE Standard 1474.1). *Note:* The ATS subsystem also typically includes manual and automatic routing functions.

Auxiliary Wayside System: A backup or secondary train control system capable of providing full or partial ATP for trains not equipped with train-borne CBTC equipment and/or trains with partially or totally inoperative train-born CBTC equipment. The auxiliary wayside system may include train-borne equipment and may also provide broken rail detection (IEEE Standard 1474.1).

Availability: Ability to be in a state to perform as required (IEC 600050-192:2015, 192-01-23). *Note:* Availability depends on the combined characteristics of the reliability, recoverability, and maintainability of the item, and maintenance support performance.

Capability: Measure of capacity and ability of an entity (system person or organization) to achieve its objectives (ISO 55000). *Note:* Asset management capabilities include processes, resources, competences, and technologies to enable the effective and efficient development and delivery of asset management plans and asset life activities, and their continual improvement.

Competence: Ability to apply knowledge and skills to achieve intended results (ISO 55000).

Component: Sub-device above the integration level of the smallest replaceable unit of a system in service or maintenance (ISO 55000).

Communications-Based Train Control (CBTC): A continuous ATC system using high-resolution train location determination, independent of track circuits; continuous, high-capacity, bi-directional train-to-wayside data communications; and train-borne and wayside processors capable of implementing vital functions (IEEE Standard 1474.1).

Commuter Rail: A passenger railroad service that operates within metropolitan areas on trackage that usually is part of the general railroad system. The operations, primarily for commuters, are generally run as part of a regional system that is publicly owned or by a railroad company as part of its overall service (IEEE Standard 1474.1).

Configuration: A characteristic of a system element, or project artifact, describing their maturity or performance (INCOSE, 2015).

Critical Asset: Asset having the potential to significantly impact the achievement of the organization's objectives (ISO 55000). *Note:* Assets can be safety-critical, environmental-critical, or performance-critical and can relate to legal, regulatory, or statutory requirements. Critical assets can refer to those assets necessary to provide services to critical customers. Asset systems can be distinguished as being critical in a similar manner to individual assets.

Critical Systems: 1) System having the potential for serious impact on the users or environment, due to factors including safety, performance, and security; 2) items (e.g., functions, parts, software, characteristics, processes) having significant effect on the product realization and use of the product, including safety, performance, form, fit, function, producibility, service life, etc., that require specific actions to ensure they are adequately managed (ISO 24765). EXAMPLE: Safety critical items, fracture critical items, mission critical items, key characteristics.

Criticality: Degree of impact that a requirement, module, error, fault, failure, or other item has on the development or operation of a system (ISO 24765).

Cybersecurity (Cyberspace Security): Preservation of confidentiality, integrity, and availability of information in the cyberspace (ISO 27032). *Note:* Other properties such as authenticity, accountability, non-repudiation, and reliability can also be involved. Adapted from the definition for information security in ISO/IEC 27000:2009.

Cyberspace: Complex environment resulting from the interaction of people, software, and services on the Internet by means of technology devices and networks connected to it that does not exist in any physical form (ISO 27032).

Data: 1) Representation of facts, concepts, or instructions in a manner suitable for communication, interpretation, or processing by humans or by automatic means; 2) collection of values assigned to base measures, derived measures and/or indicators; 3) representations of information dealt with by information systems and users thereof; 4) reinterpretable representation of information in a formalized manner suitable for communication, interpretation, or processing (ISO 24765).

Diagnostics: Programs executed to check the health of the device either periodically or randomly (IEEE Standard C37.1).

Direct Recipient: An entity that receives federal financial assistance directly from FTA.

Dwell Time: The time a transit unit (vehicle or train) spends at a station or stop, measured as the interval between its stopping and starting (IEEE Standard 1474.1).

Element: See System Element.

Enabling System: System that supports a system of interest during its lifecycle stages but does not necessarily contribute to its function during operation (ISO 15288).

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

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

Environment: Context determining the setting and circumstances of all influences upon a system (ISO 15288)

Fail Safe: A design philosophy applied to safety-critical systems such that the result of hardware failure or the effect of software error either prohibit the system from assuming or maintaining an unsafe state or cause the system to assume a state known to be safe (IEEE Standard 1474.1).

Failure: Termination of the ability of a system to perform a required function or its inability to perform within previously specified limits; an externally-visible deviation from the system's specification (ISO 24765).

Group TAM Plan: A single TAM Plan developed by a sponsor on behalf of at least one Tier II provider.

Headway: Time interval between the passing of the front ends of successive vehicles or trains moving along the same lane or track in the same direction (IEEE Standard 1474.1).

Heavy Rail Transit: A mode of rail rapid transit generally characterized by fully grade-separated construction, operating on exclusive right-of-way, with station platforms at the floor level of the vehicles (IEEE Standard 1474.1).

Hierarchy: Structure of a system whose components are ranked into levels of subordination for communication purposes according to specific rules (ISO/IEC 2382).

Horizon Period: The fixed period of time within which a transit provider will evaluate the performance of its TAM Plan.

Implementation Strategy: A transit provider's approach to carrying out TAM practices, including establishing a schedule, accountabilities, tasks, dependencies, and roles and responsibilities.

Information Asset: Knowledge or data that has value to the individual or organization (ISO/IEC 27032). *Note:* Adapted from ISO/IEC 27000:2009.

Information Technology: Resources required to acquire, process, store, and disseminate information (ISO/IEC TR 90006). *Note:* Includes communication technology and the composite term information and communication technology.

Interface: A shared boundary between two functional units, defined by functional characteristics, common physical interconnection characteristics, signal characteristics, or other characteristics, as appropriate (ISO 2382-1).

Interlocking: An arrangement of switch, lock, and signal devices located where rail tracks cross, join, or separate. The devices are interconnected in such a way that their movements must succeed each other in a predefined order, thereby preventing opposing or conflicting train movements (IEEE Standard 1474.1).

Internet of Things (IoT): An infrastructure of interconnected objects, people, systems, and information resources together with intelligent services that allows them to process information of the physical and the virtual world and react (ISO 20924).

Interoperability: Capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units (ISO/IEC 2382).

Investment Prioritization: A transit provider's ranking of capital projects or programs to achieve or maintain a state of good repair. An investment prioritization is based on financial resources from all sources that a transit provider reasonably anticipates will be available over the TAM Plan horizon period.

Key Performance Indicator: Indicator selected by the top management to evaluate the performance of the business management systems (ISO/TS 22163).

Life Cycle: Evolution of a system, product, service, project, or other human-made entity from conception through retirement (ISO 15288).

Life Cycle Cost: Total cost of acquisition and ownership of a system over its entire life; includes all costs associated with the system and its use in the concept, development, production, utilization, support and retirement stages (INCOSE, 2015).

Life Cycle Costing: Process of economic analysis to assess the cost of an item over its life cycle or a portion thereof (IEC 60050).

Light Rail Transit: A mode of rail transit characterized by its ability to operate on exclusive rights-of-way, street running, center reservation running, and grade crossings, and boarding and discharge passengers at track or vehicle floor level (IEEE Standard 1474.1).

Maintenance: Combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required (IEC 60050). *Note:* Management is assumed to include supervision activities.

Measures of Effectiveness: Measures that define the information needs of decision-makers with respect to system effectiveness to meet operational expectations (INCOSE, 2015).

Measures of Performance: Measures that define key performance characteristics a system should have when fielded and operated in its intended operating environment (INCOSE, 2015).

Network: An entity that connects endpoints and sources to destinations and may itself act as a value added element in the IoT system or services (ISO 20924).

Obsolescence (See Technological Obsolescence): Loss of ability of an item to perform satisfactorily due to changes in performance requirements (ISO 15686).

Operator: Individual or organization that performs the operation of a system (ISO 15288).

Optimize: Achieve by a quantitative or qualitative method, as appropriate, the best value compromise between conflicting factors such as performance, cost and retained risk within any non-negotiable constraints (Publicly Available Specification 55-1).

Organization: Person or a group of people and facilities with an arrangement of responsibilities, authorities, and relationships (adapted by INCOSE, 2015, from ISO 9001).

Performance: A measurable result (ISO 55000). *Note:* Performance can relate either to quantitative or qualitative findings. Performance can relate to the management of activities, processes, products (including services), systems, or organizations. For the purposes of asset management, performance can relate to assets in their ability to fulfill requirements or objectives.

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

Performance Management: A strategic approach that uses system information to make investment and policy decisions to achieve performance goals. Performance management is systematically applied; a regular ongoing process that provides key information to help decision- makers understand the consequences of investment decisions across multiple markets; improves communications among decision-makers, stakeholders, and the traveling public; ensures targets and measures are developed in cooperative partnerships and based on data and objective information.

Process: Set of interrelated or interacting activities that transform inputs into outputs (ISO 15288).

Project Management: Planning, organizing, monitoring, controlling, and reporting of all aspects of a project, and the motivation of all those involved in it to achieve the project objectives (ISO 10006).

Product: Result of a process (ISO 15288).

Project: Endeavor with defined start and finish criteria undertaken to create a product or service in accordance with specified resources and requirements (ISO 15288).

Redundancy: Existence of a system of more than one means of accomplishing a given function (IEEE Standard 1474.1).

Reliability: Probability that a system will perform its intended functions without failure, within design parameters, under specific operating conditions, and for a specific period of time (IEEE Standard 1474.1).

Requirement: Statement that translates or expresses a need and its associated constraints and conditions (ISO 15288).

Resource: Asset used or consumed during execution of a process (ISO 15288).

Retirement: Withdrawal of active support by the operations and maintenance organization, partial or total replacement by a new system, or installation of an upgraded system (ISO 15288).

Return on Investment: Ratio of revenue output (product or service) to development and production costs, which determines whether an organization benefits from performing an action to produce something (ISO/IEC 24765.5 FCD; ISO/IEC/IEEE 24765).

Risk: Effect of uncertainty on objectives (ISO 15288).

Risk Management: Process through which risks are identified, assessed, and managed. Approaches can range from completely ad hoc to formal but share the same fundamentals. Most importantly, primary objective for any approach is to improve the performance of the agency as a whole and individual business areas. Each approach seeks to anticipate risks and opportunities and then develop management strategies to minimize the occurrence of negative events. More information about risk management is provided in Section 2.

Safety: Freedom from unacceptable risk of harm (IEC 62278).

Safety Critical: 1) Term applied to a system or function, the correct performance of which is critical to the safety of personnel and/or equipment; 2) term applied to a system or function, the incorrect performance of which may result in hazard (IEEE Standard 1474.1).

Service: Performance of activities, work, or duties (ISO 15288).

Software Element: System element that is software (ISO 12207).

Software Engineering: Application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of software; the application of engineering to software (ISO 12207).

Software Item: Source code, object code, control data, or a collection of these items (ISO 12207).

Software Product: Set of computer programs and procedures, possibly associated documentation and data (ISO 12207).

Software System: System for which software is of primary importance to stakeholders (ISO 12207).

Software System Element: Member of a set of assets that constitutes a software system (ISO 12207).

Stage: Period within the life cycle of an entity that relates to the state of its description or realization (ISO 15288).

Stakeholder: Individual or organization having a right, share, claim, or interest in a system or in its possession of characteristics that meet their needs and expectations (ISO 15288).

State of Good Repair: Condition in which a capital asset can operate at a full level of performance. A capital asset is in a state of good repair when that asset:

Is able to perform its designed function

Does not pose a known unacceptable safety risk

Its life cycle investments must have been met or recovered.

Strategic Asset Management Plan (also see Asset Management Strategy): Documented information that specifies how organizational objectives are to be converted into asset management objectives, the approach for developing asset management plans, and the role of the asset management system in supporting achievement of the asset management objectives (ISO 55000). *Note:* A strategic asset management plan is derived from the organizational (strategic) plan. A Strategic Asset Management Plan may be contained in, or may be a subsidiary plan of, the organizational plan.

System: Combination of interacting elements organized to achieve one or more stated purposes (ISO 15288). *Note:* A system may be considered as a product or as the services it provides. In practice the interpretation of its meaning is frequently clarified by the use of an associate noun (for example, aircraft system). Alternatively, the word "system" is substituted by a context-dependent synonym (for example, aircraft), although this potentially obscures a system principles perspective. A complete system includes all of the associated equipment, facilities, material, computer programs, firmware, technical documentation, services, and personnel required for operations and support to the degree necessary for self-sufficient use in its intended environment.

System Element: Member of a set of elements that constitutes a system (ISO 15288). *Note:* A system element is a discrete part of a system that can be implemented to fulfill specified requirements. A system element can be hardware, software, data, humans, processes (for example, processes for providing service to users), procedures, (for example, operator instructions), facilities, materials, and naturally occurring entities (for example, water, organisms, minerals), or any combination.

System Life Cycle: The evolution with time of a system of interest from conception to retirement (INCOSE, 2015).

System of Interest: System whose life cycle is under consideration (ISO 12207).

System of Systems: Set of systems that integrates or interoperates to provide a unique capability that none of the constituent systems can accomplish on its own (ISO 12207).

System Safety: Application of engineering and management principles, criteria, and techniques to optimize all aspects of safety within the constraints of operational effectiveness, time, and costs, throughout all phases of the system life cycle (IEEE Standard 1474.1).

Systems Engineering: Interdisciplinary approach governing the total technical and managerial effort required to transform a set of stakeholders needs, expectations, and constraints into a solution and to support that solution through its life (ISO 15288).

Task: Required, recommended, or permissible action intended to contribute to the achievement of one or more outcomes of a process (ISO 15288).

Taxonomy: Controlled vocabulary for classification purposes and creating hierarchical structures.

Technological Obsolescence: Displacement of an established technical solution in a marketplace as a result of major technological developments or improvements (ISO/TR 18492).

Technical Processes: Processes used to define requirements for a system, transform requirements into an effective product, permit consistent reproduction of the product where necessary, use the product to provide the required services, sustain the provision of those services, and dispose of the product when it is retired from service (INCOSE Systems Engineering Handbook, 2015).

Total Cost of Ownership: Reflects the total estimated capital and operations and maintenance costs associated with an asset throughout its life cycle (including the cost to design/procure, use/operate, maintain/monitor, rehabilitate, and dispose/reconstruct/replace. The total cost of ownership should be represented in an asset's Life Cycle Management Plan.

Traceability: Degree to which a relationship can be established among two or more logical entities, especially entities having a predecessor-successor or master-subordinate relationship to one another, such as requirements, system elements, verifications, or tasks (ISO 12207). Example: software features and test cases typically are traced to software requirements.

Transit System: Organized set of interacting parts capable of performing one or more stated functions. Parts include infrastructure, electrical and/or mechanical equipment, hardware, software, information, personnel, processes, procedures, and other support components required to perform one or more stated functions (FTA TAM Systems Handbook).

User: Individual or group that interacts with a system or benefits from a system during its use (ISO 15288).

Validation: Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled (ISO 15288).

Value: A measure of worth (e.g., benefit divided by cost) of a specific product or service by a customer, and potentially other stakeholder and is a function of 1) the product's usefulness in satisfying a customer need, 2) the relative importance of the need being satisfied, (3) the availability of the product relative to when it is needed, and 4) the cost of ownership to the customer (McManus, 2004).

Variability: For a product line, refers to characteristics that may differ among members of the line (ISO 26550 2nd CD).

Variability Constraints: Denotes constraint relationships between a variant and variation point, between two variants, and between two variation points (ISO 26550 2nd CD).

Verification: Confirmation, through the provision of objective evidence, that specified requirements have been fulfilled (ISO 15288). *Note:* Verification is a set of activities that compares a system or system elements against the required characteristics; may include but is not limited to specified requirements, design description, and the system itself (INCOSE, 2015).

Vital Function: A function in a safety-critical system that is required to be implemented in a fail-safe manner (IEEE Standard 1474.1).

Waste: Work that adds no value to the product or service in the eyes of the customer (Womack and Jones, 1996).

APPENDIX
C

Appendix A to Part 625

Examples of Asset Categories, Asset Classes, and Individual Assets

Asset Category	Asset Class	Individual Asset
Equipment	Construction	• Crane Prime Mover
	Maintenance	• Vehicle Lift Track Geometry Car
	Non-revenue Service Vehicles	• Tow Truck Emergency Response Vehicle • Supervisor Car • Track Maintenance Vehicle
Rolling Stock	Buses	• 40-ft Bus 60-ft Articulated Bus
	Other Passenger Vehicles	• Cutaway • Van • Minivan
	Railcars	• Light Rail Vehicle Commuter Rail Locomotive
	Ferries	• Ferry Boat
Infrastructure	Systems (Asset class included in this document)	• Signal substation
	Fixed Guideway	• Track Segment • Ballast Segment • Exclusive Bus Right-of-Way Segment
	Power (Asset class included in this document)	• Catenary Segment • Third-Rail Segment
	Structures	• Bridge Tunnel Elevated Structure
Facilities	Support Facilities	• Maintenance Facilities • Administrative Facilities
	Passenger Facilities	• Rail Terminals • Bus Transfer Stations
	Parking Facilities	• Parking Garages • Park-and-Ride Lots

APPENDIX D

Example of Key Traction Power Substation Equipment Assets by Substation Type

The power supply feeding into a traction power substation (TPSS) can be either alternating current (AC) or direct current (DC). The two different types of AC substations are supply and booster. Supply substations get supply power from a utility; booster substations do not. Tie-breaker substations also exist on both AC and DC transit systems. DC substations have equipment similar to AC substations but include additional equipment to change the AC utility supply power to DC for use by the transit system. Following are examples of key substation equipment assets by substation type.

AC Supply Substation

- Utility disconnect switch or circuit breaker
- Utility metering equipment
- Main circuit breaker
- Step down transformer
- Transformer secondary circuit breaker
- AC distribution switchgear (contains the distribution circuit breakers and control equipment)
- Line side distribution disconnect switches (may be at substation or along the alignment)
- Lightning arresters
- Ground bus
- Remote circuit breaker control and mimic panel
- Rail return bus
- Battery bank (backup control power)
- Battery charger
- SCADA system (provides remote indication and control of substation status and operation)
- Ground and test devices (modified circuit breakers used to allow safe maintenance)
- Circuit breaker test stations
- Communications node equipment

AC Booster Substation

- Auto-transformer circuit breaker
- Traction auto-transformer
- AC distribution switchgear (contains distribution circuit breakers and control equipment)
- Line side distribution disconnect switches (may be at substation or along alignment)
- Lightning arresters
- Ground bus
- Remote circuit breaker control and mimic panel
- Rail return bus
- Battery bank (backup control power)
- Battery charger
- SCADA system (provides remote indication and control of substation status and operation)
- Ground and test devices (modified circuit breakers used to allow safe maintenance)
- Circuit breaker test stations
- Communications node equipment

AC Tie-Breaker Substation

- AC distribution switchgear (contains distribution circuit breakers and control equipment)
- Line side distribution disconnect switches (may be at substation or along alignment)
- Lightning arresters
- Ground bus
- Remote circuit breaker control and mimic panel
- Rail return bus
- Battery bank (backup control power)
- Battery charger
- SCADA system (provides remote indication and control of substation status and operation)
- Ground and test devices (modified circuit breakers used to allow safe maintenance)
- Circuit breaker test stations
- Communications node equipment

DC Substation

- Utility disconnect switch or circuit breaker
- Utility metering equipment
- Main circuit breaker
- Step down transformer (depends upon utility service voltage)
- Transformer secondary circuit breaker
- AC distribution switchgear (contains distribution circuit breakers and control equipment)
- Rectifier Transformer (reduces utility voltage where necessary and changes phase relationship to allow more efficient conversion)
- Traction rectifier (typically, a diode type [single direction, uncontrolled] rectifier, but sometimes thyristors [single direction, controlled] are used in place of diode to allow better voltage control [bi-directional rectifiers also exist but are not common in the US])
- DC distribution switchgear
- Line side distribution disconnect switches (may be at substation or along alignment)
- Lightning arresters
- Ground bus
- Remote circuit breaker control and mimic panels (one for AC and one for DC)
- Rail return bus
- Battery bank (backup control power)
- Battery charger
- SCADA system (provides remote indication and control of substation status and operation)
- Ground and test devices for AC and DC switchgear (modified circuit breakers used to allow safe maintenance)
- Circuit breaker test stations for AC and DC switchgear
- Communications node equipment

APPENDIX

E

Crosswalk – TAM Systems Asset Classes, FTA Standard Cost Categories, and TERM and NTD AIM

Transit System Asset Classes	FTA Standard Cost Categories for Capital Projects (TPE & TPM – New/Small Starts)	TERM (TBP – C&P Report/ TERM Lite)	NTD—AIM (TBP – NTD AIM/Final Rule)
Vehicle Control and Signaling	[50.01] Train Control and Signals [50.02] Traffic Signals and Crossing Protection	[31000] Train Control	Form A20—Train Control & Signaling Systems
Traction Power and Electrification	[50.03 & 50.04] Traction Power Supply & Distribution	[32000] Electrification	Form A20—Traction Power System
Communications and Control	[50.05] Communications	[33000] Communications	Not Available
Fare Collection	[50.06] Fare Collection System and Equipment	[34000 & 35000] Revenue Collection	Not Available
Information Technology/Business Applications	Possibly under "Communications"	[37000] ITS and under "Communications"	Not Available
Tunnel Support	Not Available	[36000] Utilities	Not Available

AIM = Asset Inventory Module
C&P = Conditions and Performance
TBP = FTA Office of Budget and Policy
TERM = Transit Economic Requirements Model
TPE = FTA Office of Planning and Environment
TPM = FTA Office of Program Management

APPENDIX F

Transit Systems Condition Assessment Methodologies and Performance Monitoring for Selected Subsystems and System Elements

Asset Class	System Type/ Subsystem	Asset	Condition Assessment Method			Obsolescence	Performance Monitoring			
			Visual	Age/Life Cycle	Life-to-Date Usage		Electronic Monitoring Devices	Testing	Trouble Ticket	Unscheduled Maintenance
Train Control		Relays	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Activity✓	Activity✓	Activity✓
		Switches	Nothing to report	Nothing to report	Activity✓	Nothing to report	Nothing to report	Activity✓	Activity✓	Activity✓
	Grade Crossing Mechanisms		Activity✓	Activity ✓	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report
	Communications Hardware	Office	Nothing to report	Activity✓	Nothing to report	Activity✓	Activity✓	Nothing to report	Activity✓	Activity✓
		On-board Vehicles	Nothing to report	Activity✓	Nothing to report	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report
	Wayside Equipment		Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Activity✓	Nothing to report	Nothing to report
	Cabling		Nothing to report	Activity✓	Nothing to report	Nothing to report	Activity✓	Nothing to report	Activity✓	Activity✓
Traction Power	Substation Traction Power	Alternating Current (AC) High-Voltage (HV) Switchgear	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report
		Direct Current (DC) Rectifier	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report
		DC Switchgear	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report
		Transformer	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Activity✓	Nothing to report	Nothing to report
	Cabling	Cabling	Nothing to report	Activity✓	Nothing to report	Nothing to report	Activity✓	Nothing to report	Activity✓	Activity✓
	Electric Traction Third Rail	AC High-tension Equipment	Activity✓	Activity✓	A✓	Nothing to report	Activity✓	Activity✓	Activity✓	Activity✓
		Electric Traction Lighting	Activity✓	Activity✓	A✓	Nothing to report	Activity✓	Activity✓	Activity✓	Activity✓
		Electric Traction/ Motor/ Generator	Activity✓	Activity✓	A✓	Nothing to report	Activity✓	Activity✓	Activity✓	Activity✓
		Third Rail	Activity✓	Activity✓	A✓	Nothing to report	Activity✓	Activity✓	Activity✓	Activity✓
	Electric Traction Overhead Contact System	Overhead Contact Wire	Nothing to report	Activity✓	A✓	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report
		Messenger Wire	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report
		Poles/Masts	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report

Asset Class	System Type/ Subsystem	Asset	Condition Assessment Method			Obsolescence	Performance Monitoring			
			Visual	Age/Life Cycle	Life-to-Date Usage		Electronic Monitoring Devices	Testing	Trouble Ticket	Unscheduled Maintenance
Communications and Control	Control, Monitoring and Data Storage	Facility	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓
		Servers	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Activity✓	Activity✓
		Other Hardware (e.g., monitors, access controllers, PCs, laptops)	Nothing to report	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report
		Cabling	Nothing to report	Activity✓	Nothing to report	Nothing to report	Activity✓	Nothing to report	Activity✓	Activity✓
		Uninterrupted Power Supply (UPS) Units	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report
	Networks	Cabling	Nothing to report	Activity✓	Nothing to report	Nothing to report	Activity✓	Nothing to report	Activity✓	Activity✓
		Hardware	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Antennas	Activity✓	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report	Nothing to report
	Closed-Circuit Television (CCTV) System	Hardware	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
	Public Address System	Hardware	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
	Radio System	Hardware	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
	Telephone System	Hardware	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
	Supervisory Control and Data Acquisition (SCADA)	SCADA Servers	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Remote Terminal Units	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		SCADA Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
	Access Control/ intrusion Detection	Hardware	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
Revenue Collection		Hardware	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report

Asset Class	System Type/ Subsystem	Asset	Condition Assessment Method			Obsolescence	Performance Monitoring			
			Visual	Age/Life Cycle	Life-to-Date Usage		Electronic Monitoring Devices	Testing	Trouble Ticket	Unscheduled Maintenance
Information Technology/ Business Applications		Hardware	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
Tunnel Support	Tunnel Ventilation and Exhaust	Electromechanical Equipment	Activity✓	Activity✓	Activity✓	Nothing to report	Activity✓	Activity✓	Activity✓	Activit✓
		Cabling	Nothing to report	Activity✓	Nothing to report	Nothing to report	Activity✓	Nothing to report	Activity✓	Activity✓
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report
	Electrification and Lighting	Electromechanical Equipment	Activity✓	Activity✓	Activity✓	Nothing to report	Activity✓	Activity✓	Activity✓	Activity✓
		Cabling	Nothing to report	Activity✓	Nothing to report	Nothing to report	Activity✓	Nothing to report	Activity✓	Activity✓
		Software	Nothing to report	Nothing to report	Nothing to report	Activity✓	Activity✓	Nothing to report	Nothing to report	Nothing to report

APPENDIX
G

Sample of Fire Life Safety Systems

Emergency Power Systems

- Blue light stations and emergency trip station systems
- Emergency generators for backup power
- Uninterrupted power supply
- Emergency lighting systems

Communications Systems

- Emergency radio systems
- Emergency telephones
- Seismic sensor system
- SCADA system

Fire Detection/Suppression Systems

- Automatic closing fire assembly systems
- Fire alarm systems (heat/smoke)
- Fire control panels
- Fire pumps
- Sprinkler systems
- Wet standpipe systems
- Undercar deluge systems

Gas Detection Systems

- Gas control units
- Gas detectors

Smoke Evacuation System

- Emergency ventilation fans and air handling units

Emergency Evacuation

- Emergency egress hatches
- Emergency evacuation signage

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