ABSTRACT

Maintenance is an essential aspect of any transit system’s operation. There are many reasons for performing maintenance including ensuring the safety of passengers, the proper operation of the equipment and to realize maximum Return on the Investment (ROI) across the entire life cycle of an asset. Maintenance-related issues vary during each of the three life cycle phases (Design and Construction, Sustainment and Operations, and Disposal). Many, if not most, of the decisions made to address these issues have significant impact on the safety, reliability and maintainability of the equipment as well as a dramatic effect on the overall maintenance cost for that asset. Unfortunately, many transit organizations are neither aware of the issues they should be addressing during each life cycle phase nor what tools or techniques to employ to arrive at the answer that meets their organization’s unique goals and requirements.

This paper will outline the maintenance-related issues that transit organizations should be addressing in each of the three asset life cycle phases and provide recommended tools or techniques available to assist in addressing those issues.

INTRODUCTION

Billions of dollars are spent each year by North American transit agencies to maintain their transportation assets. Aside from payroll, maintenance costs are typically at the top of the list of transit agency operating expenditures. But does that significant investment of resources provide the level of service and ROI that transit agencies as well as their regulatory authorities such as the Federal Railroad Administration (FRA) and Federal Transit Administration (FTA) desire? With ridership reaching all-time highs in recent years, transit assets are being pushed to their operational utilization limits. To ensure transit agencies continue operating at peak efficiency, maintenance programs must provide the desired results whether those results are measured against a financial target, equipment reliability or asset availability. Unfortunately, for a multitude of reasons, many maintenance programs are not realizing the uniform level of reliability and failure prevention desired. The problem is typically not caused by a failure to perform the prescribed maintenance tasks. The issue is much more subtle and based in a common misperception that once established, an asset’s initial maintenance program will serve it well for the life of the equipment. Just like with the human body, the actions and activities required to stay healthy during different phases of life will vary. The same is true for transit assets. The actions necessary to maintain an asset’s health (or “state of good repair”) across their life cycle will vary, too. Before addressing the techniques available to identify the most appropriate maintenance requirements to maintain the health of transit assets at various stages of the aging process across their lifecycle, we need to review some basic maintenance terms.

WHAT IS MAINTENANCE?

There are a variety of maintenance actions performed at transit agencies every day. From routine inspections to more complicated diesel engine overhauls, the scope and complexity of maintenance tasks vary greatly. Identifying a definition that encompasses the diversity of different maintenance activities is important if we are going to approach this topic with a common understanding.

The United States Department of Defense (DoD) uses this definition: “Maintenance tasks restore performance, safety, and reliability of materiel to their inherent levels when deterioration has occurred.” 1 Another reference defines maintenance as “A science, an art, but above all a philosophy.”2 That definition does not provide transit agencies much of a foundation upon which to build a maintenance program. The groundbreaking book Reliability-Centered Maintenance written by Stanley Nowlan and Howard Heap of United Airlines for the
Department of Defense more than 35 years ago does not even provide a definition for the term maintenance.3

My preferred maintenance definition and, perhaps, one of the most succinct definitions on this topic that I have seen is:

“Maintenance consists of actions taken to ensure systems and equipment provide their intended functions when required.”4

Preserving the function of asset systems, subsystems and equipment is the objective of maintenance. With that definition in mind, all maintenance tasks will fit into one of the following three categories:

- Tasks performed to correct unsatisfactory conditions whether those actions are to restore a loss or a degradation of functionality. These tasks are typically referred to as Corrective Maintenance or repairs.
- Actions taken to prevent an unsatisfactory condition from occurring. These tasks usually involve either inspections or tests to identify the onset of a potentially unsatisfactory condition or a preemptive action when the onset of potential failure cannot be identified by a test or inspection. These type tasks are called Preventive or Planned Maintenance.
- Steps taken to either eliminate a faulty design that is detrimentally impacting functionality, or to upgrade the functionality of an asset. These tasks are known as Alternative Maintenance actions because they make an alteration to asset’s original design functionality.

<table>
<thead>
<tr>
<th>Types of Maintenance</th>
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<tr>
<td><strong>Corrective Maintenance</strong></td>
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<td>o Objective: Correct unsatisfactory conditions</td>
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<td>o Schedule: As required (i.e., unplanned)</td>
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<tr>
<td><strong>Preventive Maintenance</strong></td>
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<tr>
<td>o Objective: Prevent unsatisfactory conditions</td>
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<td>o Schedule: Periodic (i.e., scheduled)</td>
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<tr>
<td><strong>Alternative Maintenance</strong></td>
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<td>o Objective: Eliminate unsatisfactory designs</td>
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<td>o Schedule: One-time</td>
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Figure 1. Three Types of Maintenance

**Evolving Maintenance Methodologies**

Over the past 60 or so years, maintenance methodologies have evolved significantly as both technology and our understanding of the engineering associated with maintenance has improved. During the 1940s and early 1950s, maintenance consisted primarily of repairing assets after they failed. Some industries at the time utilized overhauls, an early form of preventive maintenance, typically consisting of component replacements without any data or technical support justifying the replacement. During the 1950s preventive maintenance techniques were being explored and Time-Based Maintenance (TBM) was introduced. TBM maintenance techniques were not only implemented in industry but, with the advent of automobile periodic maintenance plans, were introduced for the first time into everyday life, too.

Assets became significantly more complicated in the 1960s and TBM techniques were not able to keep up with the advancements being made in asset design. With the advancement in technology, the causes of system failure were less apparent than before and a new method was required to support system functionality. Reliability-Centered Maintenance (RCM), which United Airlines introduced with the arrival of the 747 aircraft, was that process. RCM is a systematic process that identifies the function of systems and components, evaluates what causes failure of those functions and analyzes what can be done in a preventive maintenance program to prevent or mitigate the loss of system functionality to an acceptable level. As computer use advanced, more sophisticated diagnostic methodologies developed in the 1980s. This enabled Condition Based Maintenance (CBM) techniques and CBM technology to enhance RCM-based preventive maintenance procedures. CBM technologies enabled non-intrusive, and in many situations more detailed, evaluation of systems, subsystems and components to identify the onset of failure earlier, more accurately and with less risk to the equipment and maintenance personnel. When properly employed, RCM often identifies opportunities to extend preventive maintenance task scheduling frequency thereby reducing maintenance costs, freeing resources to be used elsewhere and eliminating unnecessary intrusion into equipment. CBM technology contributes significantly to enhance and improve the efficiency and effectiveness of the RCM-based maintenance procedures.
MAINTENANCE LIFE CYCLES

The Merriam-Webster Dictionary defines ‘life cycle’ as “a series of stages through which something (as an individual, culture, or manufactured product) passes during its lifetime.” It is easy for us to recognize the changes in our children, or other family members, as they go through various stages in their lifetime. Sometimes, however, recognizing the changes that our assets pass through during their lifetime is not as obvious and often slips by unnoticed. Not paying attention to the changes that your children experience as they grow is a tragedy for any parent. For transit agency operations and maintenance managers to not recognize the changes their assets are undergoing will lead to increased costs, decreased reliability, reduced asset availability and, many times, loss of public support and revenue. Monitoring and managing assets at various stages of their life cycle, therefore, is of critical importance and has lead in recent years to the development of very specific Asset Management methodologies and standards. The first such standard was created in the United Kingdom as the Publicly Available Standard (PAS) 55 series and, based on the success of that standard series, an International Standard (ISO-55000 series) was released earlier this year.

To effectively manage the Maintenance Life Cycle, the life cycle stages need to be clearly identified. Human life cycle stages are well known: infant, toddler, child, teen-ager, adult and senior citizen (or geriatric). For assets, however, the stages vary widely depending on which reference to which you refer. The U.S. Department of Defense uses five distinct stages in their weapons acquisition life cycle:
- Concept Refinement
- Technology Development
- Systems Development and Demonstration
- Production and Deployment
- Operations and Support
- Disposal

PAS 55 describes four specific ‘life cycle activities’:
- Acquire/create
- Utilize
- Maintain
- Renew/dispose

Other references provide variations on these stages and definitions to support their specific frame of reference or methodology. For the purposes of maintaining transit related assets, I believe, three life cycle phases is all that is necessary:
- Design and Construction
- Sustainment and Operations
- Disposal

Design and Construction Phase

The Design and Construction Phase is where it all starts! From identification of the initial idea to post-construction delivery and testing, there is a great deal of thought and work that occurs during this phase. This phase could easily be divided into many additional stages as many organizations have done in their asset management process. The advantage in establishing more stages during the preliminary Design and Construction is it enables more scrutiny and attention to detail during this critical part of an asset’s life. Even if a new asset is very similar to previous assets in a transit agency’s inventory, there are few shortcuts that can be taken during this phase if your expectation for a high quality, durable and long-lasting asset will be realized. Similar to parenting children, the investment made early in life reaps the longest lasting benefits. The same can be true with transit assets. If design for reliability, maintainability and availability are overlooked, or not given the due diligence it deserves, the agency will be plagued with poor reliability and failures for the life of the equipment.

Sustainment and Operations Phase

It is during the Sustainment and Operations Phase that both expected and unexpected stresses are imposed on transit assets. If properly designed and built, expected stresses will have been identified and addressed in the design of the equipment or maintenance program. The unexpected stresses, however, will test the durability of an asset as well as the patience of the maintenance manager, shop floor maintainers and transit passengers. Careful monitoring of potential failures, failure modes and the impact current maintenance procedures have on asset reliability is instrumental in realizing the benefits of good design. A preventive maintenance program can only maintain an asset at the inherent reliability levels established during system design. Failure to periodically and systematically re-evaluate the maintenance needs of an aging transit fleet will realize reliability levels considerably below those inherent design levels.

Disposal Phase

As a transit asset approaches its ‘end of life’ many believe that attention to what and how maintenance is performed will no longer be necessary. Nothing could farther from the truth! As we have all witnessed with older family members or friends, visits to the doctor typically do not decrease but multiply as humans reach ‘the golden years.’ The
same is often true with transportation assets and more attention is required on the maintenance performed not less, even if only to make a conscious decision on whether an expensive procedure is truly necessary or whether a waiver should be pursued if that procedure is required for safety or by regulation.

The issues faced in each life cycle phase are unique and different, and the perspective applied to address each challenge will vary with each transit agency. The overall goals of the maintenance strategy decisions made during each of these three life cycle phases, however, are very similar. Each life cycle phase requires critical maintenance planning decisions to:

- Achieve safe, reliable and consistent performance.
- Attain full equipment life.
- Realize maximum Return on Investment (ROI).

DESIGN AND CONSTRUCTION PHASE MAINTENANCE CONSIDERATIONS

New transit asset procurement is one of, if not, the largest capital expense an agency makes. Not only is the procurement a huge monetary expense but it also involves significant number of agency personnel to assist in the design of the new equipment. The pressure to deliver a winning, low-cost, highly reliable and comfortable-to-ride equipment design to the manufacturer is incredibly high. There’s a great deal on the line during the Design Phase!

Typically, much of the attention in transit asset design is paid to internal and external esthetics of the new equipment. Having an appealing design that attracts customers is an important perspective for the design team to address during this phase but it is not the only important consideration to be addressed during asset design. Even with the most stylish design over the life of that asset, styles and tastes will change and what is cutting edge style today is often out of touch in just a few short years.

On the other hand, maintainability decisions made during the Design and Construction Phase will impact the long-term maintenance cost and reliability for the life of the equipment. Opinions on the exact details of how much of a long-term impact the maintainability decisions will have vary but Benjamin S. Blanchard in his book Design and Manage to Life Cycle Costs states that ninety-five percent (95%) of an asset’s life cycle cost is fixed during the Design and Construction Phase as depicted in Figure 2.5

![Figure 2. Life Cycle Cost Commitment](image)

As stated earlier, once the design is finalized, preventive maintenance can only maintain equipment reliability at inherent design levels. Realizing an improvement in the inherent design level, will require a modification or change to the equipment design, which is typically quite costly. Therefore, maintainability-related decisions, made during the Design and Construction Phase are the most important.

Some may ask “What is maintainability and is it any different than maintenance?

Maintainability certainly is different from maintenance and should be a critical consideration during this life cycle phase. Maintainability describes the ability of an asset to be maintained while maintenance describes the actions taken to ensure systems and equipment provide their intended functions when required. Maintainability is a design parameter and maintenance tasks are a result of that design. If an asset is not designed for maintainability, regardless of the quality of the maintenance procedures, maintenance costs will be higher and the asset reliability will be lower than if maintainability had been properly addressed.

So, how is maintainability designed into an asset? It begins with the basics! The following are maintainability and maintenance-related items that should be considered during the Design and Construction Phase:

- System and component function
- Functional loss or degradation criteria
- Requirements and tasks to maintain functionality
- Maintenance minimized or maintenance friendly designs
- Design changes to reduce failure causes
- Modifying designs to enhance maintenance execution
- Maintenance execution recording techniques
- Equipment failure data recording processes/systems

System and Component Function

Basic functions for systems and components are readily obvious. For example, everyone understands the function of a Heating, Ventilation and Air Conditioning (HVAC) system. The underlying functions that contribute to the proper operation of the HVAC system, such as the lower coolant pressure cut-off device, may not be as obvious and therefore can be overlooked. All system and component functions should be identified so that essential systems and those systems that will cause the greatest disruption to service if they fail can be prioritized for preventive maintenance actions.

Functional Loss or Degradation Criteria

The expression ‘…beauty is in the eye of the beholder’ applies here, but only in the reverse. What one considers a degrading failure may be considered still functional to someone else. It is essential that the functional loss or degradation criteria is clearly established for each system or component function that will be evaluated for preventive maintenance tasks so that the maintenance can be applied uniformly and impartially.

Requirements and Tasks To Maintain Functionality

Once system/component functions, priorities and functional failure/degradation criteria have been established, an assessment on whether those failures can be prevented should be conducted. Not all failures can be prevented and sometimes the right maintenance strategy is to allow something to fail if the consequences are negligible. For higher priority failure consequences, such as failures that result in risk of injury to personnel, every attempt should be made to prevent that failure through an appropriate preventive maintenance procedure.

Maintenance Minimized or Maintenance Friendly Designs

Once the routine preventive maintenance procedures have been identified, a concerted effort should be made to ensure the maintenance can be performed without extreme difficulty and without placing the maintenance personnel at risk. Also, if a change in the asset design can be identified that will eliminate the need for a preventive maintenance procedure or that can minimize preventive maintenance it should be identified at this step, as well.

Design Changes To Reduce Failure Causes

It was stated earlier that not all failures can be prevented but asset design should not be inducing failures, either. If a failure cause is linked to the design of an asset’s system or component, a design change should be identified and pursued to eliminate that failure causing issue.

Modifying Designs To Enhance Maintenance Execution

Do you remember how easy it was to perform routine maintenance on the old Volkswagen Beetle? Everything was accessible and easy to reach for the maintainer. As assets became more complicated, the accessibility to perform maintenance has often been detrimentally impacted. Easy to perform maintenance procedures, whether by the installation of connection ports for electronic readings that eliminates the need to open live electrical panels, or by placing oil drain ports in easily accessible locations, increase the likelihood that the maintenance task will be completed correctly.

Maintenance Execution Recording Techniques

There is an old expression, “…the work is not done until the documentation is completed.” The Design and Construction Phase is the time to identify the maintenance tasks to be performed to ensure functionality of the asset, as well as to determine how maintenance personnel will record the status of those scheduled maintenance procedures. Whether using hand-held devices, an application on a mobile phone or voice recording of conditions found and status of work completion, the easier it is for the craftsman to record the information the more likely it will be reported accurately and on time.

Equipment Failure Data Recording Process/Systems

Monitoring the failure trends and taking action when the initial maintenance program does not
adequately address a particular failure is essential to the long-term health of any asset. It is critical to ensure the method used to capture and record failure information, once the asset is operational, is easy to use and serves the purposes of the entire organization not just the maintenance team. Several very robust Computerized Maintenance Management Systems (CMMS) are available today that support everyone from the shop floor to the Corporate Suite in recording and displaying necessary information. Decisions on what CMMS system will be used should be included in the asset Design and Construction Phase.

**DESIGN AND CONSTRUCTION PHASE MAINTENANCE TOOLS AND TECHNIQUES**

The scope and volume of items to consider in preparing a transit asset for maintenance success during the Design and Construction Phase can appear overwhelming. The techniques and tools available to assist agencies in ensuring they optimize their maintenance program for safe, reliable and consistent operations are well proven and time tested.

‘Classic’ Reliability-Centered Maintenance

RCM evolved from the study of maintenance initiated as a joint Federal Aviation Administration (FAA), United Airlines and Boeing effort under the title of the Maintenance Steering Group (MSG) in the mid-1960s. Still a mainstay in the aviation community, RCM has been successfully implemented in a wide variety of industries from DoD acquisition to nuclear power to commercial manufacturing. Several years ago the Federal Railroad Administration (FRA) authorized railroads relief from the requirements of 49 CFR 238 if justified with a detailed RCM analysis per the methodology prescribed in 49 CFR 238 Appendix E.

Several of the Design and Construction Maintenance Considerations identified above are addressed when ‘Classic’ RCM is utilized for initial maintenance requirements definition. The objective of the RCM process is to ensure functionality of an asset’s systems and equipment. The first step in the RCM process requires a developer to define system and equipment functions and their functional failures. The next two RCM process steps, Failure Modes and Effects Analysis and Logic Tree Analysis, address the second and third Design and Construction Phase Considerations by identifying failure or degradation, criteria as well as the specific maintenance requirements and tasks to maintain functionality.

Using a ‘Classic RCM’ approach is a fundamental and first step to laying a solid foundation for an asset’s maintenance program early in the design process. Only after the necessary maintenance requirements are identified via the Logic Tree Analysis can the Maintainability be effectively analyzed.

**Maintainability Review**

As important as it is to have the correct design, it is just as essential to verify that design supports the agency’s Reliability, Availability and Maintainability (RAM) goals. If system and equipment maintainability is ignored until after the first assets are delivered, the costs to correct with design flaws preventing performance of preventive maintenance procedures can be significant. Maintainability should be reviewed as soon as possible following identification of an asset’s maintenance requirements.

The Maintainability Review assesses an asset’s design for ease of maintenance, as well as evaluating impacts to maintainers, such as risks while performing maintenance and accessibility to locations requiring maintenance action. Preventive maintenance, including daily inspections and periodic preventive maintenance tasks, in addition to potential corrective maintenance actions should be included in this review. During the Maintainability Review, the assessor should be familiar with the failure modes identified during the RCM development so design changes that will prevent the causes of those failure modes, where possible, can also evaluated.

Maintainability Reviews should be formal design reviews starting early in the systems development process and continuing through production and delivery. Often it is beneficial to have an impartial and competent third party perform this review using a closed loop process where deficiencies identified are entered into a tracking system and require either a design change or program waiver to be resolved.

**Computerized Maintenance Management System (CMMS)**

Recording ‘as found condition’ data as well as establishing a repository for information concerning failures plus the ability to track and trend failure status is a critical component of any agency’s maintenance and reliability program. Many agencies already have a CMMS but with the introduction of a new asset there are several questions that should be
addressed. Such as, will it be compatible with the software systems on the new asset? Does it provide for ‘Bluetooth’ connectivity from the maintenance shop floor? Is it easy for the maintenance crews to use to input data? Does it provide the maintenance managers the capability to trend failure information, identify problems in parts availability and have access to maintenance scheduling information they need?

When a new asset is being brought into an existing inventory, compatibility and usability of an existing CMMS should not be overlooked. If an agency does not yet have a CMMS, this may also be the time to research the advantages of having a CMMS to realize improved maintenance efficiency, asset reliability and to take advantage of state of the art technology, which is commonplace in today’s newer transit assets.

SEPTA Example

The Southeastern Pennsylvania Transportation Authority (SEPTA) recently introduced a new Silverliner V Railcar to their service. Their process embraced several of the Design and Construction Phase Considerations discussed here and in doing so they achieved:

- Enhanced maintainability
- Higher asset reliability
- Reduced overall maintenance costs

Their process included both maintenance and operating personnel from the earliest design steps. They also utilized advanced technology that reduced maintenance requirements, for example solid state technology for electrical control systems, and collected ‘real time’ relevant data from sub-systems which not only stored the failure information for failure analysis purposes but provided for the downloading of data via Wi-Fi connections at various locations so maintenance personnel are capable of having the information prior to the asset returning to the yard.9

SUSTAINMENT AND OPERATIONS PHASE MAINTENANCE CONSIDERATIONS

In the Sustainment and Operations Phase the perspective shifts from what ‘should be’ to ‘what is’ happening. No longer is the effort to make the design as good as it can be but the maintenance staff is now dealing with the results of the design process. Much of the maintenance program design process is speculation based on the professional acumen of those evaluating the functions, functional failures, failure modes and maintenance procedures to mitigate failures. Until the transit asset is put into service, stresses that cause failure modes will only be hypothetical. Even in the best asset maintenance program development effort, there is always room for improvement because some anticipated stresses will not be experienced, or will be experienced at a lesser degree than expected, and other stresses will be experienced that were not anticipated.

The following are maintenance improvement-related items that should be considered during the Sustainment and Operations Phase:

- Unforeseen or unplanned equipment failures
- New maintenance requirements and procedures for unanticipated repeat failures
- Failures occurring less frequently than expected
- New technology that can improve inspection accuracy or minimize burdensome tasks
- Maintenance procedure improvement to enhance reliability or reduce maintenance time

Unforeseen or Unplanned Equipment Failures

‘Murphy’s Law’ is alive and well in the transit industry. On some days, if something can go wrong, it will…but that does not mean that Murphy wins! Addressing recurring failures that were not anticipated during the Design and Construction Phase enables an agency to have a dynamic, living maintenance program that responds appropriately to changing circumstances and conditions. Similar to a doctor adjusting to changes in a patient’s life, maintenance managers must also be willing to make adjustments based on condition and failure data from their assets.

New Maintenance Requirements And Procedures For Unanticipated Repeat Failures

Modifications to upgrade asset features or to correct design flaws, in combination with unexpected recurring failures will create a nucleus for a group of new maintenance procedures to ensure functionality and reliable operations. Not every modification or unexpected failure will necessitate a new maintenance procedure. Agencies should decide, however, whether or not one is necessary.
Failures Occurring Less Frequently Than Expected

Occasionally a situation arises in which failure modes that were anticipated in the initial maintenance analysis do not occur. This could be caused by either the maintenance designed is so precise it prevents all the failures, or the asset is not experiencing the anticipated stresses which would cause failure to occur. Regardless of the reason why anticipated failures are not occurring, this is another opportunity to review and improve the Sustainment and Operations Phase maintenance plan.

New Technology That Can Improve Inspection Accuracy Or Minimize Burdensome Tasks

Technology is constantly evolving and improving. Non-intrusive maintenance tools are now available that create an opportunity to enhance a transit agency’s maintenance program to provide safer, more accurate and less burdensome maintenance procedures. One caution regarding technology, not every tool is necessarily applicable in every circumstance or environment. Caution should be applied in evaluating each maintenance technology to ensure it accurately addresses the failure modes for which the maintenance procedure was designed and does not impose an additional maintenance burden.

Maintenance Procedure Improvement To Enhance Reliability Or Reduce Maintenance Time

As the transit asset operates and maintenance is performed on a recurring basis, efficiencies will be realized in how it is performed. Those efficiencies can either enhance quality or reduced time to perform a task with a consistently high quality. In either case, it is to the transit agency’s advantage to leverage these efficiencies and standardize the improvements across the maintenance department.

SUSTAINMENT AND OPERATIONS PHASE TOOLS AND TECHNIQUES

To have a dynamic, living maintenance program that is responsive to trends observed in asset reliability and failure data, a degree of vigilance must be applied. Reviewing data only once or twice a year may expose you to months of lost availability and disgruntled passengers that erodes public confidence in your service. A highly effective Sustainment and Operations Phase maintenance program establishes recurring processes to review and respond to trends in operations and failure data. Two tools that can assist significantly in addressing the Considerations identified during this Phase. They are:

‘In-Service’ RCM Analysis

Addressing the Sustainment and Operations Considerations may initially appear as arduous as the Design and Construction Considerations but that is not the case. During the Design and Construction Phase ‘Classic’ RCM was recommended to identify maintenance requirements for new transit assets. A parallel process, ‘In-Service’ RCM, has been used since the 1980s to review and improve existing maintenance programs with great success. The ‘In-Service’ RCM process was originally outlined in the U.S. Navy's Reliability-Centered Maintenance Handbook written by Thomas D. Matteson, a retired United Airlines Vice President for Maintenance Administration, and one of the authors of the original RCM process. The Navy called their ‘In-Service’ RCM process ‘Backfit RCM’. A simplified diagram of the ‘In-Service’ RCM process is provided in Figure 3.

Figure 3. Basic ‘In-Service’ RCM Process

The ‘In-Service’ RCM process is designed to review legacy maintenance requirements and procedures using actual operational use and failure data to validate the ‘applicability’ and effectiveness’ of each requirement. The Navy began using this process on their ship and submarine requirements in 1997 and it is still in use today. Since that time, in addition to improving the technical quality of hundreds of thousands of procedures, the engineering rigor and discipline of this process has led to periodicity adjustments and elimination of unnecessary maintenance requirements resulting in a significant (almost 50%) reduction in maintenance requirements without any degradation in safety, operational availability or reliability of ship systems.
The individuals who perform routine maintenance tasks everyday are an incredible source of information on efficiencies and improvements to those tasks. Many times tremendous efficiencies and improvements in how a preventive maintenance procedure can be performed are un-realized because either no one asked or there is not a standardized process to forward a recommended change within an organization. Establishing a process whereby shop floor personnel can submit recommended changes, have those changes reviewed for technical merit and accuracy and approved for implementation is another technique available during the Sustainment and Operations Phase to continuously improve an agency’s maintenance plan.

Amtrak Example

Since 2006, The National Railroad Passenger Corporation (Amtrak) has been employing both the ‘In-Service’ RCM process and a formalized Technical Feedback System to their tremendous advantage. The maintenance requirement improvements realized on Amtrak’s Acela fleet alone enabled a 15% increase in asset availability and improved equipment reliability more than 30%. Those improvements contributed significantly to more than $19.6M annual revenue increase on the Acela service alone. Their Technical Feedback System has also identified dozens of improvements in both maintenance procedure and technology improvements across the Amtrak network.

DISPOSAL MAINTENANCE CONSIDERATIONS

As an asset reaches the end of its useful life, some will be of a mind that maintenance procedures are no longer as important as they are earlier in life. If anything, the procedures performed to keep an aging asset serviceable will probably increase not decrease in importance and number of tasks. As with the human body, the older we get aches and pains become more common and our resistance to stress decreases. The same can often happen with transit assets and therefore a more careful and critical eye must be applied to inspection and operational information.

Once a decision has been made to dispose of an asset, or a fleet of assets, there are several items of consideration that are unique to this Phase that bear review and deliberation. Disposal Phase Considerations include:

- What are critical maintenance tasks to be performed prior to retirement and what tasks can be deferred on an ‘as needed’ basis?
- Which components should be removed to have as spares when an asset is retired?
- Hazardous material, liquids and gas eradication upon retirement

Critical Maintenance Tasks

Once an asset has been identified for disposal our instinct is to reduce both labor and financial asset-related expenditures. As long as that equipment is in service, however, there will be a need to perform the standard maintenance package. If a significant costly maintenance requirement, whether preventive or corrective, is identified for a disposal-designated asset a decision must be made. There may be a reason to perform that procedure but it may be in the best interest of the agency to request a waiver or pursue an early retirement so that expenditure can be avoided. That type analysis and decision is unique to this Phase although commonplace for maintenance managers during this stage of an asset’s life cycle.

Spare Parts Recovery

Many times there is overlap on parts and equipage between fleet classes. A review of what equipment on the disposal-designated asset is common to other assets in an agency’s fleet should be conducted well in advance of the actual retirement date. Where there are overlapping parts or equipage, maintenance managers should make a decision on which, if any, parts should be stripped and placed back in circulation before the asset is removed for disposal. Some parts may not be worth salvaging from the retiring asset but others, especially long-lead time items or parts whose manufacture is no longer making that part can be very valuable additions to the local parts inventory.

Hazardous Material Eradication

The removal of hazardous material, liquids and gases may be included in an asset’s disposal contract but if not, an agency will need to evaluate what hazardous materials they are going to remove prior to transfer of the assets and which ones will be necessary to be retained onboard during the transfer. The costs associated with an agency removing hazardous materials may be considerably less than contracting it
to another organization or having it included in the disposal contract.

CONCLUSIONS

Maintenance-related issues vary during each of the three life cycle phases, Design and Construction, Sustainment and Operations, and Disposal. Maintenance managers need to be cognizant of the unique issues each life cycle phase presents and what tools are available, or what type questions to be asking, to ensure an asset’s maintenance program is providing a safe, reliable and cost effective product for their riders.

The tools and techniques identified to assist in making improvements in the maintenance plan during each Phase have been utilized in a variety of applications and are ‘time tested’ with great success. I have observed first hand that pursuing the steps outlined in this paper provide a significant return on investment and can enable a substantial extension on the life of a transit asset.
