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MANAGEMENT MANUAL

GUIDELINES FOR THE NAVAL AVIATION RELIABILITY-CENTERED MAINTENANCE PROCESS

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INTRODUCTION

1.1 PURPOSE

Reliability Centered Maintenance (RCM) is an analytical process to determine the appropriate failure management strategies, including PM requirements and other actions that are warranted to ensure safe operations and cost-wise readiness. This process of developing PM requirements, with an auditable documentation package, is based on the reliability of the various components, the severity of the consequences related to safety and mission if failure occurs, and the cost effectiveness of the task. This manual is the primary guidance document for anyone tasked with implementing an RCM program or performing an RCM analysis on Naval Air Systems Command (NAVAIR) managed equipment. It covers the following subjects:

- RCM Program Management
- RCM Analysis Process
- Implementation of Analysis Results, and
- RCM Program Sustainment.

NAVAIRINST 4790.20 (series), *Reliability-Centered Maintenance Program*, states that, "The NAVAIR RCM Program is applicable to all new procurement and in-service aircraft, engines, systems (i.e., weapons, aircrew escape systems, avionics, and electrical systems), and Support Equipment (SE) (i.e., avionics support equipment, non-avionics support equipment, and aircraft launch/recovery equipment) including their modification, during all life cycle phases and levels of maintenance. RCM principles shall be applied (as part of the systems engineering process) to ensure safety and cost-wise readiness through determination of appropriate failure management strategies. These strategies ensure the proper balance of preventive maintenance (PM) tasks, prognostics and diagnostics (i.e., predictive and detective sensing devices), corrective maintenance, operational procedures, maintenance improvements, design changes, and training."

This manual does not attempt to provide the complete background, history, or philosophy of the RCM process. Various books and training courses are available on the RCM philosophy and its development and applications. A good understanding of the underlying tenets of RCM should be obtained before attempting to implement an RCM program.

1.2 SCOPE

This manual describes the process used to develop all PM requirements for NAVAIR aircraft, engines, aircrew escape systems, weapon systems, aircraft launch and recovery equipment, and support equipment.

1.3 DEFINITIONS

- **Acceptable Probability of Failure –** The probability of a given failure mode occurring during a defined period that a program is willing to accept.
- **Actual Probability of Failure –** The predicted or demonstrated probability of a given failure mode occurring during a defined period in the operating environment.
- **Age Exploration (AE)** –A process used to collect specific data to replace estimated or assumed values, optimize or validate data used and assumptions made during an RCM analysis. This may include exploration of characteristics or effects of age or usage on a given failure mode.
- **Conditional Probability of Failure –** The probability that a failure will occur in a specific period provided that the item concerned has survived to the beginning of that period.
- **Criticality Analysis** – A procedure that prioritizes each failure mode identified in the FMEA according to the combined influence of its severity and its probability of occurrence.
- **End Item –** An assembly of hardware elements that is not used to assemble a higher level physical item, and is ready for its intended use.
- **Failure Consequences –** The impact of functional failure (including secondary damage) caused by failure mode(s) based on evidence of failure and adverse effect on Safety, Environment, Operations, and Economics.
- **Failure Effects –** The result of a functional failure on surrounding items, the functional capability of the end item, and hazards to personnel and the environment.
- **Failure Finding Task –** A preventive maintenance task performed at a specified interval to determine whether a hidden failure has occurred.
- **Failure Mode** – A specific physical condition that can result in a particular functional failure.
- **Failure Mode and Effects Analysis (FMEA)** – A process used to determine the function(s) of each item, the functional failures associated with each function, the failure modes that have the potential to cause each functional failure, and the effect and severity of each failure mode.
- **Failure Mode, Effects and Criticality Analysis (FMECA) –** A process which combines a Failure Mode and Effects Analysis (FMEA) and a Criticality Analysis (CA).
- **Function** – An intended purpose of an item as described by a required standard of performance.
- **Functional Failure** – The inability of an item to perform a specific function within specified limits.
- **Hard Time Task –** The scheduled removal of an item, or a restorative action at some specified maximum operating limit to mitigate the risk of functional failure to an acceptable level.

- **Hardware Partition**– The logical hierarchical division of an asset into progressively smaller elements to show relationships among systems, subsystems, and components. Also known as Hardware Breakdown.
- **Hidden Failure** – A functional failure whose effects are not apparent to the operating crew under normal circumstances.
- **Lubrication Task** – The periodic application of a lubricant to items that require lubrication for proper operation or to prevent premature functional failures.
- **Non-significant Function (NSF) –** A function whose failure will have no adverse safety, environmental, operational, or economic effects.
- **On Condition Task –** A periodic or continuous inspection designed to detect a potential failure condition and allow correction prior to functional failure.
- **Other Action** – A term used to indicate that some action (other than PM) is either required or desired to most effectively deal with the consequences of a failure mode.
- **Potential Failure** – A definable and detectable condition that indicates that a functional failure will occur.
- **Preventive Maintenance (PM) –** Actions performed prior to functional failure (multiple failures or demand requirements for hidden failures) to achieve the desired level of safety and reliability for an item.
- **Prognostics and Health Management (PHM) Systems** – Diagnostic or prognostic devices and systems that are used to monitor equipment condition and provide indications to the operator or maintainer. These systems may also initiate automatic actions to deal with the condition(s) sensed or predicted.
- **Servicing Task** – The replenishment of consumable materials that are depleted during normal operations.
- **Severity Classification –** A category assigned to a failure mode based on the impacts of its potential effects.
- **Significant Function (SF)** – A function whose failure will have adverse effect with regard to Safety, Environment, Operations, and Economics.

1.4 ACRONYMS

AE	Age Exploration
AEB	Age Exploration Bulletin
AEP	Age Exploration Plan
APML	Assistant Program Manager for Logistics
APMS&E	Assistant Program Manager, Systems and Engineering
BUNO	Bureau Number
CBM	Condition-Based Maintenance
CBM+	Condition Based Maintenance Plus

*	**CMMS**	Computerized Maintenance Management System
*	**COMNAVAIRFOR**	Commander, Naval Air Forces
*	**CPC**	Corrosion Preventive Compound
*	**DMMH**	Direct Maintenance Man-hours
*	**ECA**	Equipment Condition Analysis
*	**ECP**	Engineering Change Proposal
*	**EHR**	Equipment History Record, or Explosive Hazard Report
*	**EI**	Engineering Investigation
*	**FH**	Flight Hour
*	**FMEA**	Failure Modes and Effects Analysis
*	**FMECA**	Failure Modes, Effects, and Criticality Analysis
*	**FST**	Fleet Support Team
*	**HMR**	Hazardous Material Report
*	**IMC**	Integrated Maintenance Concept
*	**IPT**	Integrated Program Team
*	**IRCMS**	Integrated Reliability-Centered Maintenance System
*	**IT**	Information Technology
*	**MMH**	Maintenance Man Hours
*	**MRC**	Maintenance Requirement Card
*	**MTBF**	Mean Time Between Failure
*	**MTBMA**	Mean Time Between Maintenance Actions
*	**MTBCA**	Mean Time Between Corrective Actions
*	**MTTF**	Mean Time To Failure
*	**NADEP**	Naval Air Depot
*	**NALCOMIS**	Naval Aviation Logistics Command Management Information System
*	**NALDA**	Naval Aviation Logistics Data Analysis
*	**NAMP**	Naval Aviation Maintenance Program
*	**NATOPS**	Naval Air Training and Operating Procedures Standardization
*	**NAVAIR**	Naval Air Systems Command
*	**NDI**	Non-destructive Inspection
*	**NMC**	Not Mission Capable
*	**NOMMP**	Naval Ordnance Maintenance Management Program
*	**NSF**	Non-significant Function

∗	**OEM**	Original Equipment Manufacturer
∗	**OPNAV**	Office of the Chief of Naval Operations
∗	**P & P**	Propulsion and Power
∗	**PF**	Potential (failure)-to-Functional (failure) interval
∗	**PHM**	Prognostics and Health Management
∗	**PM**	Preventive Maintenance
∗	**PMA**	Program Manager, Air
∗	**PMC**	Partially Mission Capable
∗	**POA&M**	Plan of Action and Milestones
∗	**QDR**	Quality Deficiency Report
∗	**RCM**	Reliability-Centered Maintenance
∗	**SF**	Significant Function
∗	**TPDR**	Technical Publication Deficiency Report
∗	**WUC**	Work Unit Code

1.5 REFERENCE DOCUMENTS

∗	**COMNAVAIRFORINST 4790.2**	Naval Aviation Maintenance Program
∗	**OPNAVINST 8000.16**	Naval Ordnance Maintenance Management Program
∗	**NAVAIRINST 4790.20**	Reliability-Centered Maintenance Program
∗	**NAVAIRINST 4790.3**	Aeronautical Time Cycle Management Program
∗	**NAVAIRINST 13120.1**	Fixed Wing Aircraft Structural Life Limits
∗	**NAVAIRINST 13130.1**	Rotary Wing Aircraft Structural Life Limits
∗	**MIL-HDBK-217**	Reliability Prediction of Electronic Equipment
∗	**(SAE) JA1011**	Society of Automotive Engineers Evaluation Criteria for RCM Processes
∗	**(SAE) JA1012**	Society of Automotive Engineers Guide to the RCM Standard
∗	**DoDI 4151.22**	Condition Based Maintenance Plus (CBM+) for Materiel Maintenance
∗	**DoDI 5000.02**	Operation of the Defense Acquisition System
∗	**CBM+ DoD Guidebook**	Condition Based Maintenance Plus Department of Defense Guidebook of May 2008

*	**DOD Supportability Guide**	Designing and Assessing Supportability in DoD Weapon Systems: A Guide to Increased Reliability and Reduced Logistics Footprint of 24 October 2003

SECTION II

RCM PROGRAM MANAGEMENT

2.1 INTRODUCTION

Implementation of an RCM program encompasses much more than just performing RCM analysis. It is a major undertaking that requires significant planning and project management efforts. This section addresses many of the issues that need to be considered prior to implementing an RCM program. Figure 2-1 illustrates the overall RCM program process and highlights the RCM Plan and Hardware Partition blocks covered in this section.

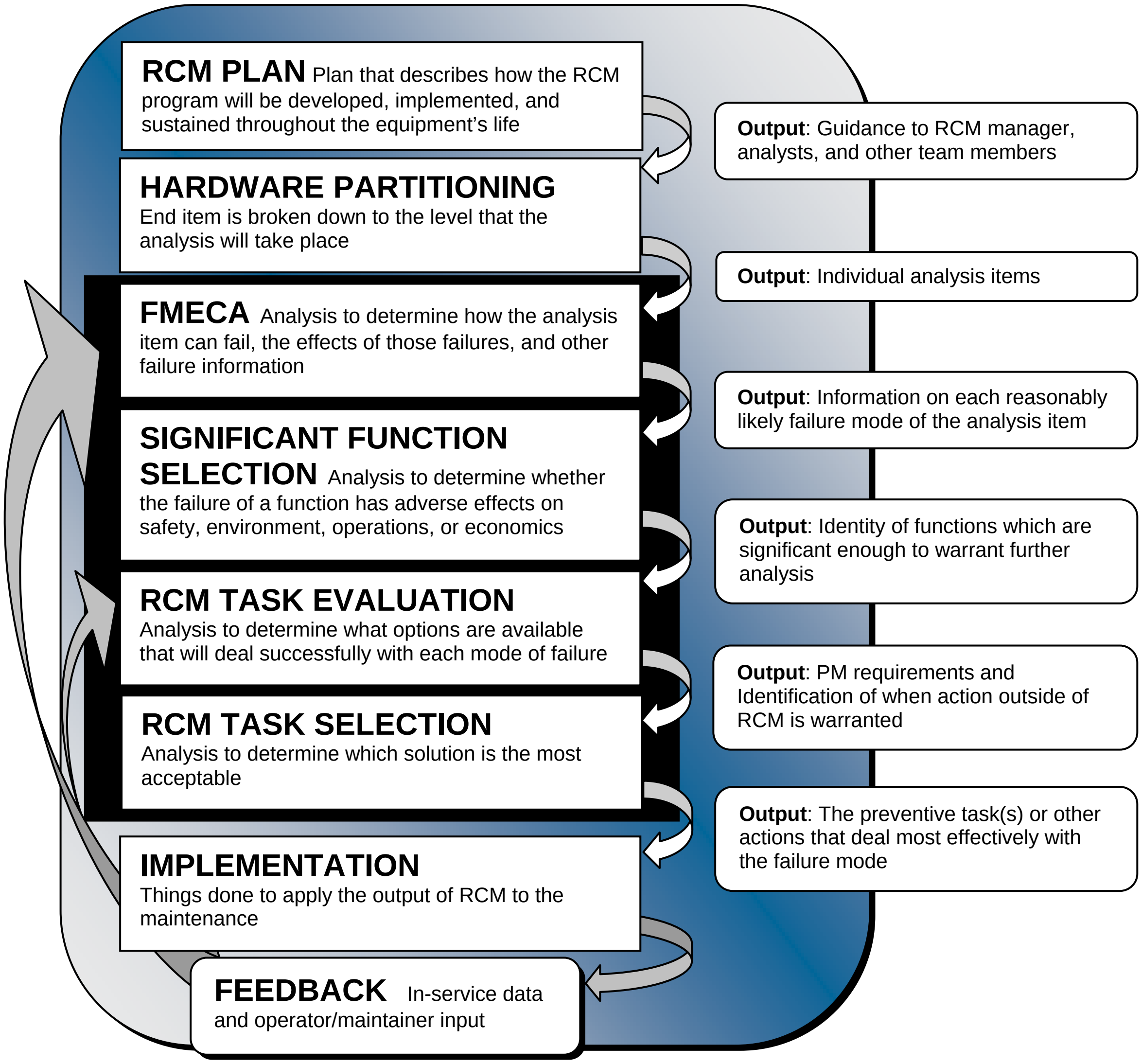


Figure 2-1 RCM Process Map

As with any large project, substantial up front planning is required for it to be successful. An RCM Program Plan, which is required by NAVAIRINST 4790.20 (series), is the means by which this planning effort is accomplished and recorded. The RCM Program Plan must address, at a minimum, the implementation and sustainment issues discussed in this section. It should also include a Plan of Action and Milestones (POA&M) to outline key events that will occur when a particular activity is started or completed, as well as a listing of project tasks and priorities for the execution year. A five year budget requirement projection should be included, not only from a financial standpoint, but also outlining manpower requirements. The POA&M should include contingencies to handle budgetary fluctuations. The plan may also address how an RCM program will interface with other organizational elements, such as system safety, logistics, and human factors groups. The Naval Aviation Maintenance Program (NAMP), COMNAVAIRFORINST 4790.2, and the Naval Ordnance Maintenance Management Program (NOMMP), OPNAVINST 8000.16, offer guidance by establishing standard maintenance policy for aircraft and ordnance respectively. They should be referred to during development and execution of the RCM Program Plan to help create a positive working relationship between the RCM program and the maintenance program. The RCM Program Plan must be updated periodically to reflect changes in program requirements or transition between life cycle phases. Examples of approved RCM Program Plans can be obtained from the RCM Steering Committee.

One valuable resource for assisting in the implementation of an RCM program is the NAVAIR RCM Steering Committee. It is made up of RCM experts from several NAVAIR programs that represent various assets such as aircraft, engines, weapon systems, aircraft launch and recovery equipment and support equipment. It provides a forum through which a wide variety of RCM-related subjects are discussed, including the development and refinement of processes and tools used to implement and sustain RCM programs. One objective of the Steering Committee is the exchange of technical information among personnel assigned to perform RCM. Another objective is to work in cooperation with all Navy maintenance organizations, other Department of Defense agencies, academia, industry, and international armed forces and organizations to standardize the RCM procedure and to share information for the benefit of all concerned. The Steering Committee is available to provide assistance to any program tasked with implementing and sustaining an RCM program.

Supplements to this guide may be issued to provide specific additional guidance related to unique equipment or commodities. Recognizing specific competency responsibilities and authority, this additional guidance will provide commodity or competency-unique data, criteria and analysis techniques. Any supplement to this guide should be coordinated with the NAVAIR RCM Steering Committee to ensure it properly supports the general RCM process.

The NAVAIR RCM Steering Committee may be reached via the NAVAIR RCM web site at http://www.navair.navy.mil/logistics/rcm/.

2.2 RCM DURING ACQUISITION PHASES

The guide is written with emphasis on life-cycle application of RCM during the in-service phase of the equipment's life cycle. However, RCM application can and should begin with conceptual design and continue until the retirement of the equipment from service. The effectiveness of equipment from a safety, operational, and cost standpoint can be improved by establishing the RCM program during the early phases of a design and development effort. Using RCM as a part of the design process allows early identification of failure modes that may result in expensive or difficult preventive maintenance action; require design mitigation or elimination; or benefit from introduction of design features such as easy access, PHM technology, easy inspection, interchangeability, or technological advances. RCM activity will be dependent on the program and the Acquisition Program Phase.

The DoD Guide “Designing and Assessing Supportability in DoD Weapon Systems: A Guide to Increased Reliability and Reduced Logistics Footprint” of 24 October 2003, provides a template to use in defining and assessing program activities to meet DoD policy requirements throughout the weapon system life cycle. Emphasis is placed on designing for increased reliability and reduced logistics footprint and on providing for effective product support through performance-based logistics (PBL) strategies. The Guide stresses the use of RCM for a system-based methodical approach to determine causes of failure, failure consequences, and to identify the most applicable and effective maintenance task(s). Appropriate use of proactive maintenance technologies embodied in diagnostics and prognostics, integrating on-board and off-board monitoring, testing, data collection, and analysis capabilities are also addressed to significantly enhance system maintainability and overall supportability. These practices include enhanced prognosis/diagnosis techniques, failure trend analysis, electronic portable or point-of-maintenance aids, corrosion mitigation, serial item management, automatic identification technology, and data-driven interactive maintenance training. Ultimately, these practices can increase operational availability and readiness at a reduced cost throughout the weapon system life cycle.

The following is provided as guidance for appropriate activity prior to various Acquisition Milestones.

2.2.1 Prior to Milestone A (Materiel Solution Analysis Phase)

- RCM should be identified as an integral function of the Maintenance Planning/Supportability Analysis and Design Interface Activities.
- A "functional" failure modes and effects analysis methodology should be established to identify likely failure scenarios that can be mitigated or eliminated through design.
- An initial RCM approach to identify strategies for preventive maintenance development and to review lessons learned from current systems should be established. RCM analysis at the "functional" level may be able to identify likely PM strategies and requirements that can be incorporated into the design requirements.
- Potential technologies to improve/optimize preventive maintenance and failure management should be identified.
- Potential analytical tools, including their required functionality and interfaces, should be identified for evaluation and selection.
- RCM concepts should be integral and influential in the maintenance concept development.
- Organization responsibilities should be clearly established (both contractor and government) for conduct and assessment of the RCM efforts including any required areas of integration across organizations.

- Adequate resources should be identified for RCM efforts, including technology maturation for new initiatives, in subsequent phases.
- Design trade-off analyses should consider the effects on preventive maintenance and failure management using RCM concepts.

2.2.2 Prior to Milestone B (Technology Development Phase)

- A Baseline Comparison Study of preventive maintenance requirements (using like and similar equipment) should be accomplished to identify opportunities for improvements and to establish preventive maintenance supportability design or performance requirements.
- A Use Study should be accomplished to identify any issues and constraints related to performing preventative maintenance in the intended environment.
- An initial RCM plan should be developed to ensure cursory RCM design assessments (using likely failure modes and resultant preventive maintenance) are conducted consistent with the design/technology evolution to allow design influence for optimized preventive maintenance and failure management.
- The RCM Plan should clearly identify RCM Team members, organizational responsibilities, RCM candidate selection, schedule and resource requirements, supportability design constraints and requirements, ground rules and assumptions, design evaluation and trade-off processes, analysis and documentation methodologies and tools, and establish the framework of the RCM program for the life cycle of the equipment. The RCM plan should identify performance metrics for design influence and maintenance planning related to preventive maintenance and establish feedback mechanisms for results of testing or early prototype fielding efforts.
- The preventive maintenance and failure management approach should consider technological advances such as PHM to reduce reliance on physical inspections and calendar-based maintenance; and facilitate opportunistic maintenance. Design trade-off plans and processes should be in place to ensure such technologies are evaluated for life cycle cost effectiveness. Technological advances should be evaluated for any inherent risk that requires mitigation until the maturity can be adequately evaluated.
- The RCM handling of safety and environmental consequences should be established and be consistent with established design requirements for system safety and environmental hazards.
- Lessons learned from fielded programs (or other programs in development incorporating similar technological advances) should be incorporated into supportability design or performance requirements for preventive maintenance and failure management.
- An agreement and approach for development and use of the detailed FMECA data to support both Reliability and Maintainability and Supportability Analysis/RCM requirements should be established.

2.2.3 Prior to Milestone C (Engineering & Manufacturing Development Phase)

- The Baseline Comparison Study of preventive maintenance requirements should be updated as the design evolves to identify areas for improvements and to update preventive maintenance supportability design or performance requirements.
- The Use Study should be updated to identify any issues and constraints related to preventative maintenance in the intended environment as the design evolves and operational basing/deployment and training plans are developed.
- An initial "hardware" RCM analysis on the evolving design should be used to influence the design evolution to optimize preventive maintenance and failure management.
- The RCM Plan should be updated consistent with the design phase. The RCM analysis effort should be iterative and responsive to design and modification development to ensure a preventive maintenance and failure management program reflective of current configuration and with plans for update consistent with any planned product improvements. The RCM Plan should clearly identify RCM Team members, organizational responsibilities, RCM candidate selection, schedule and resource requirements, supportability design constraints and requirements, ground rules and assumptions, design evaluation and trade-off processes, analysis and documentation methodologies and tools, and establish the framework of the RCM program for the life-cycle of the equipment. Fleet user involvement should be solicited early in the analysis process.
- The preventive maintenance and failure management approach should continue to evaluate technological advances such as PHM to reduce reliance on physical inspections and calendar-based maintenance; and facilitate opportunistic maintenance. Trade-off processes should be continued to ensure such technologies are evaluated for life-cycle cost effectiveness. Technological advances with inherent risk should be mitigated and monitored until the maturity can be adequately established.
- The RCM handling of safety and environmental consequences should be consistent with established design requirements for system safety and environmental hazards.
- An agreement and approach for development and use of the FMECA and early fielding failure data to support System Safety, Reliability and Maintainability, and Supportability Analysis/RCM requirements should be established.
- Lessons learned from fielded programs and early fielding feedback (or lessons learned by other programs incorporating similar technological advances) should be incorporated into supportability design or performance requirements, or result in adjustments to preventive maintenance and failure management requirements through update of the RCM analyses.
- RCM results should be incorporated into maintenance plans and technical publications. Provisions should be in place to ensure preventive maintenance requirements are not changed without support from an updated RCM analysis.

- Resources and plans should be identified for sustainment of the RCM and preventive maintenance/failure management programs for in-service equipment. Meaningful performance metrics should be established or updated to monitor and adjust the RCM results and preventive maintenance requirements. Periodic Fleet reviews should be identified and scheduled following fielding.
- Age Exploration should be established as an integral part of the overall maintenance approach including the maturation of PHM initiatives and incorporation into technical documentation as appropriate. Opportunities for technology and reliability improvements should be identified and funded through appropriate channels.

2.2.4 During Full Rate Production and Beyond (Production & Deployment, Operations and Support, Demilitarization/Disposal Phases)

- The Baseline Comparison Study of preventive maintenance requirements should be updated, as modifications occur, to identify areas for improvements and to establish preventive maintenance supportability design requirements for modifications.
- FMECA/RCM updates should be identified and resourced for each modification. Design trade studies should be accomplished as the design or technology evolves for possible introduction of beneficial technologies or changes to the preventive maintenance or failure management approach. See Section 2.4 for further discussion.
- The RCM Plan should be maintained as the program progresses. The RCM analysis effort should be responsive to design modification development to ensure a preventive maintenance and failure management program reflective of current configuration. The RCM Plan should continue to identify current RCM Team members, organizational responsibilities, RCM candidate selection, schedule and resource requirements, supportability design constraints and requirements, ground rules and assumptions, design evaluation and trade-off processes, analysis and documentation methodologies and tools, and sustainment activities for the life cycle of the equipment. Fleet user involvement should be evident throughout the analysis and data collection process.
- The preventive maintenance and failure management approach should continue to consider technological advances, such as PHM or by using CBM+ tools, to reduce reliance on physical inspections and calendar-based maintenance during modifications. Processes should be in place to identify and consider the cost/benefit of evolving technologies for insertion into the design or maintenance processes.
- The RCM handling of safety and environmental consequences should remain consistent with established requirements for system safety and environmental hazards. Safety and environmental issue resolution should include RCM as an integral process.
- Lessons learned from similar fielded programs should be periodically reviewed for application to improve preventive maintenance and failure management.
- An effective agreement and approach for development, use, and update of the FMECA during modifications and from in-service failure data to support both

Reliability and Maintainability and Supportability Analysis/RCM requirements should be in place.

- RCM results should be incorporated into maintenance plans and technical publications. Provisions should be in place to ensure preventive maintenance requirements are not changed without support from an updated RCM analysis.
- Resources and plans should be maintained/updated for sustainment of the RCM and preventive maintenance/failure management programs for the in-service equipment. Performance metrics should be reviewed and updated. The RCM and preventive maintenance requirements should be updated (as necessary) based on the performance metrics. Fleet reviews should continue periodically. The RCM update process should be responsive to fleet inputs and findings.
- Age Exploration should continue to be integral to the overall maintenance approach, including incorporation into technical documentation as appropriate. Results of Age Exploration should be used to update the RCM and preventive maintenance requirements in a timely manner.
- RCM sustainment is required throughout the life cycle, even to the point of demilitarization and disposal of the system. Considerations for the end of the life cycle, in terms of RCM, include maintaining a level of effort to meet safety thresholds at a minimum, the potential for transitioning RCM analyses and data to follow-on programs, the historical logging of analyses, and recording of lessons learned. The level of effort to sustain the analysis as the program transitions through life cycle phases will depend on the complexity of the analysis, not the number of items in service.
- There may be value added by archiving RCM analyses, whether it be for assisting new acquisition, like and similar systems, or foreign military sales. Issues that need to be considered for archiving and sharing historical analyses should include proprietary and technical data sensitivity concerns.

2.3 RCM TEAM ESTABLISHMENT (Management, Analysis, Sustainment)

Establishment of an RCM team composed of the proper mix of personnel is paramount for achieving a cost effective life cycle maintenance program. The appropriate RCM team membership ultimately depends on a program’s specific needs and organization. Each competency is responsible for providing individuals that are certified and empowered by the governing competency to provide their competency-unique inputs to the RCM process.

The following managers should collectively identify the team of Government and contractor personnel that will be responsible for developing and implementing the RCM Program Plan, performing the initial RCM analyses, and sustaining the RCM Program:

- Program Manager, Air (PMA)
- Assistant Program Manager for Logistics (APML)
- Assistant Program Manager for Systems and Engineering (APMS&E)
- Fleet Support Team (FST) leader

2.3.1 RCM Team Composition

RCM team composition and responsibilities may include, but are not limited to, the following personnel and organizations:

2.3.1.1 Program Management

- Program Manager - Obtains all funding needed to develop, execute, and sustain the RCM program
- Assistant Program Manager, Logistics (APML) - Approves the RCM plan; ensures that failure management strategies and PM requirements are based on RCM in accordance with applicable instructions and that it is correctly integrated into the maintenance planning process
- Assistant Program Manager, Systems and Engineering (APMS&E) - Supports engineering requirements necessary to effectively conduct the RCM program
- System Safety Engineer – Supports hazard risk analysis
- Cost Analysis – Provides required program cost data

2.3.1.2 Fleet Support Team

- Leader and Sub-team Leaders - Manage assigned RCM team personnel
- RCM Implementation Manager - Serves as coordinator and approval authority for RCM analyses as defined within their respective teams
- RCM Analysts – Conduct particular RCM analysis efforts as assigned
- Reliability and Maintainability, Logistics, and Engineering personnel – Support RCM analysis efforts with supplemental engineers, logisticians, and data analysts

2.3.1.3 Competencies

Competencies required by the team to provide data and expertise in their fields may include:

- Design Interface and Maintenance Planning
- Air Vehicle Design and Integration
- Reliability & Maintainability
- Air Vehicle Structures
- Air Vehicle Systems
- Aircrew Systems
- Avionics
- Propulsion and Power (P&P)
- Weapons
- Aircraft Launch and Recovery Equipment
- Support Equipment

2.3.1.4 Original Equipment Manufacturer (OEM) or Supporting Contractors

Original Equipment Manufacturer (OEM) or Supporting Contractors Conduct or support initial and/or sustaining RCM analyses and data collection in accordance with FST/IPT and/or PMA/APML contracts.

2.3.1.5 Equipment Controlling Custodians, Operators, & Maintainers

- Provide in-service maintenance data, knowledge, and experience via FST/IPT interviews, data requests, and active participation on RCM analysis teams.
- Provide in-service maintenance data via established maintenance data systems (e.g., Naval Aviation Logistics Command Management Information System (NALCOMIS), FST Depot databases)
- Provide recommendations for improvements to established maintenance data systems
- Provide assessment of maintenance requirements resulting from RCM analysis

2.3.2 Ancillary Support Requirements

The following personnel may be required for ancillary support, but are not necessarily included in the RCM team composition:

- Information Technology (IT) personnel
- Budget personnel
- Contracts personnel

2.3.3 Knowledge and Skills Requirements

RCM team members, either individually or collectively, should possess the following knowledge and skills in order to effectively develop an RCM plan, collect data, conduct and sustain the RCM analyses:

- Project Management
- RCM decision logic
- Reliability, maintainability, maintenance, and logistics data analysis
- System supportability analysis
- Naval Aviation Maintenance Program (NAMP) policy and procedures
- Equipment functions, failures and maintenance processes
- Basic computer skills (project management, database development and management)
- Statistical techniques
- Applicable engineering analysis techniques (e.g., structural analysis, materials analysis)
- Contracting
- Financial issues

- Inspection and equipment condition monitoring techniques (e.g., Prognostics and Health Management (PHM), nondestructive inspection (NDI))
- Effective Team Operations and Interpersonal Communications

2.3.4 Contracting For RCM

Sometimes it may be necessary to contract for RCM accomplishment by the OEM or support contractors. This decision should be carefully considered to ensure the RCM analysis effort is accomplished and sustained to a level that is satisfactory to the program managers, the FST and equipment operators and maintainers. When contracting for RCM, the statement of work should utilize this guide, or SAE JA1011 and JA1012, to ensure the contractor is proposing a process that is compliant with the tenets of RCM and should reference this manual as guidance or reference. The government activity and personnel responsible for the long-term support and sustainment of the RCM program and the resulting preventive maintenance program should remain involved and provide appropriate expertise in the conduct and review of the analysis efforts. Particularly, there may be a need to ensure appropriate interaction and information is gained from the operators, maintainers, and supporting engineers and logisticians. The deliverables should be scheduled such that appropriate progress is ensured and any problems are identified before investment of resources into follow-on activities. For example, the RCM Plan should be delivered and approved before beginning the analysis effort and the FMECA data should be subject to incremental or in-process reviews to identify issues early in the process. Provisions for support and sustainment should be considered to ensure the format, content and depth of data in any deliverables ensures adequate documentation to support decisions and recommendations for future reference.

2.3.5 Conducting The Analysis

Programs may choose to organize their RCM program efforts in various ways. Successful applications of RCM have been obtained from complete organic accomplishment of the analysis and from teaming with OEM's or support contractors. Likewise, RCM has been accomplished successfully by assigning lead analysts responsible for conducting the analysis on assigned equipment and from establishing a team of people who mutually perform the analysis efforts in group settings. If accomplished using lead analysts, each lead analyst must ensure that all elements of the team necessary for successfully conducting the RCM are involved and knowledgeable of RCM in general, and the specific effort in particular. It is particularly important that operators and maintainers are primary participants in the process as they may bring unique information or perspectives that must be considered in developing the maintenance requirements. Likewise, if the analysis is conducted in a group setting, the group leader must ensure that all participants properly provide the data necessary for a complete and comprehensive analysis, and that no one element overshadows the legitimate input of others. Also, when using the group method, methodologies for collecting feedback information and responding to emergent issues that arise between group meetings must be established to ensure the integrity of the RCM-based maintenance program. Whatever method of accomplishment is chosen should be well defined, with any ground rules, in the RCM Plan.

2.4 SCOPE OF ANALYSIS

The analysis scope is the extent of the RCM analysis effort to be applied to meet program objectives. It includes the selection of hardware items for analysis; the indenture level at which analysis of the hardware will be performed; and the extent to which each item will be analyzed. The scope of analysis depends on several factors. These include, but are not limited to, the life cycle phase, the quantity, quality, and validity of any prior analyses, the effectiveness of the current maintenance program, and available resources.

The scope of the analysis drives the level of effort. The scope can range from analyzing one or two functions and selected failure modes of an in-service item during the sustaining phase to performing a complete analysis of all functions and failure modes of a new item during its acquisition. There are also many intermediate levels of analysis between the two extremes. These include analyzing high cost or high man-hour drivers, readiness degraders, items with current preventive maintenance (PM) tasks, or any combination of these.

The scope of analysis can vary widely for an item with a significant service history. For an in-service item, the quality and validity of prior analyses, the effectiveness of the current maintenance program, and the resources available will influence the scope. If a previous RCM analysis exists, even if accomplished under different guidelines, it may be used to reduce the workload of an updated analysis. A previous analysis may be used in several ways. Examples include limiting the updated analysis to hardware that has no prior analysis; updating the previous analysis to conform to new processes; to consider application of new inspection or monitoring technology; or as a data source for a complete new analysis. A combination of these may be used to some advantage. A hardware item with limited life remaining may warrant analysis of only a few specific functions. The availability of funding and trained analysts will also be major factors in determining the analysis scope.

The intent of an RCM program for a new item is to ensure that appropriate levels of safety, environmental compliance, mission accomplishment, and economy of operations are achieved. This includes identifying design shortfalls or areas for application of technology such as NDI or PHM that would lead to lower life cycle costs. An appropriate scope of analysis for a new item design is, therefore, one that encompasses the entire item.

When any of the methods described above are used to limit the scope of an analysis, extreme care must be taken to ensure that no safety/environmental or significant operational/economic issues are overlooked.

2.4.1 Determining Scope of Analysis

The process for determining the scope of an RCM analysis can be summarized as follows:

- Identify program characteristics (e.g., life-cycle stage of end item, status and availability of prior analyses, effectiveness of the current PM program, expectations from the application of RCM)

- Identify analysis approach to include:
  - Hardware breakdown
  - Level of analysis
  - Hardware to be analyzed at the selected level
  - Extent of analysis for each hardware item selected

2.4.2 Hardware Partitioning

A hardware partition is the logical division of an item into progressively smaller elements that are decreasingly complex. Typical hardware partition indenture levels, from the highest to the lowest, are identified as end item, system, subsystem and sub-subsystem (or component). All of these levels need not be defined for a given end item. However, the hardware partition should be carried down to at least the level at which the analysis will be initially performed. Level of analysis is discussed in more detail in section 2.4.3.

Clear boundaries of where an item begins and ends must be identified and documented in the RCM Program Plan's Ground Rules and Assumptions section. For example, when preparing to analyze a hydraulic flight control system, it must be determined where the flight control system ends and where the hydraulic system begins. To make this distinction, the system's interfaces must be clearly defined and logically established. A typical division of the system would place the actuator with the flight control system and the attaching tubing and connectors as components of the hydraulic system. The ultimate goal of this undertaking is to break down the hardware into units that simplify the task of clearly identifying functions, functional failures and failure modes and to ensure no subsystem or component is overlooked.

The Work Unit Code (WUC) manual is an excellent resource to utilize in partitioning a system for RCM analysis. A WUC breakdown may be useful as is, or it may require some manipulation for more efficient analysis. For example, a landing gear door may be part of the fuselage in a WUC breakdown, but it might be more efficiently analyzed as part of the landing gear system. Other hardware partitioning systems, such as the Logistic Control Number, system diagrams from technical publications, or coding systems used to assign hierarchical divisions of an asset may also provide useful starting points for a hardware partition. One advantage of using the WUC breakdown is that it can be applied directly to the NALCOMIS maintenance data collection system. If some other system is used, it may have to be "mapped" to the WUC system before NALCOMIS maintenance data can be efficiently utilized in the collation of information for RCM analysis. Conversely, system descriptions in technical publications often provide the best breakdown from a functional description perspective. Figure 2-2 illustrates an example of a hardware partition.

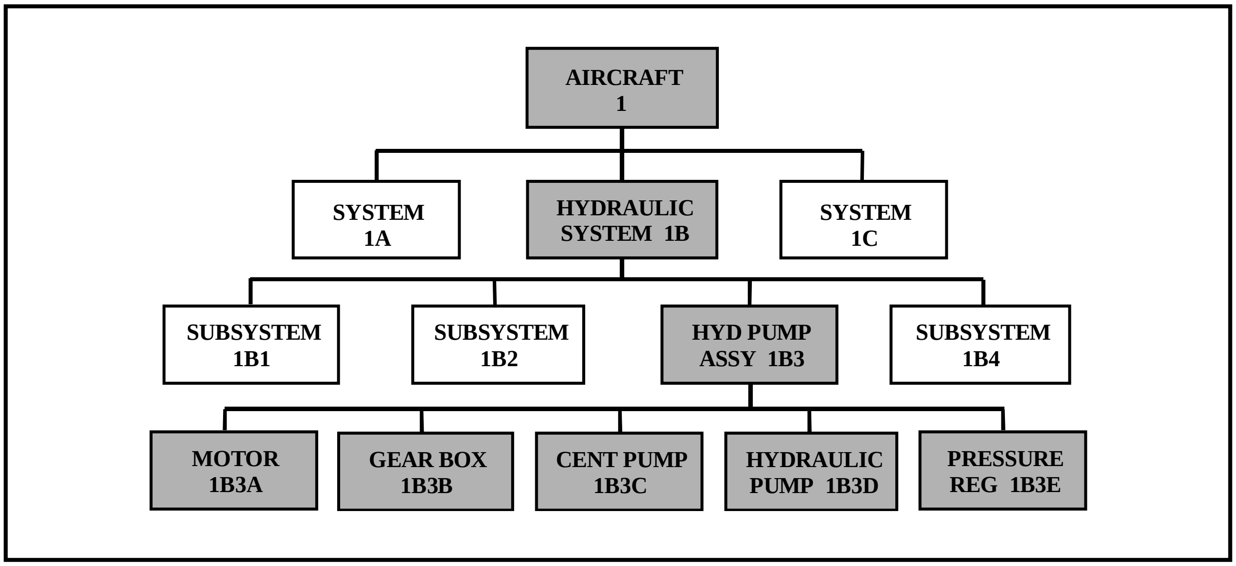


Figure 2-2 Hardware Partition Block Diagram

2.4.3 Level of Analysis

The level of analysis is the indenture level of the hardware at which the analysis will be performed. The optimum level of analysis for a given item of hardware depends on several factors. These factors include whether a complete analysis or a limited analysis will be performed, whether previous analyses exist (and to what level they were performed), and the complexity of the item being analyzed.

Careful consideration is required to choose a level of analysis that will identify a manageable number of functions and failure modes. An analysis performed at too high a level will likely become overwhelming as the relationship between functions at the high level and the many failure modes become complicated. As the effort advances from a high level to progressively lower levels, the number of functions and related failure modes identified will multiply. This eventually will have a stifling effect on the analysis. The target level will normally be a level consistent with the likely level of "on-equipment" maintenance. For example, if most maintenance is performed by replacing assemblies, the level of analysis would most likely be such that the functions and failure modes of the sub-systems comprised of these assemblies could be readily defined. This is often referred to as a "sub-system" level analysis.

Relatively simple systems, such as aircraft oxygen systems, can be analyzed at the system level. Complex systems, such as a flight control system or a landing gear system, may be better served if they are analyzed at the subsystem level. This does not apply necessarily in an instance where an analysis has been done at some other indenture level, and the data from that effort will be updated instead of performing a new analysis.

A limited analysis may be performed efficiently at lower levels, such as the assembly or component level, on specific items. If this is the case, plan to approach the analysis in such a way that it allows the effort to be expanded to a full analysis should the need arise. A preferred approach to accomplish this is to identify functions at the system or subsystem level, then analyze only failure modes of selected components within the selected subsystem. This approach may require a little more effort initially, but will save time if or when the complete analysis is performed.

Some hardware may be analyzed at multiple levels to avoid analyzing redundant functions. For example, assume that an aircraft is being analyzed at the subsystem level. Subsystems may include the wing, forward fuselage, center fuselage, and aft fuselage. Rather than analyzing the functions of the paint on each of the subsystems, the paint functions could be analyzed at airframe level while the remaining functions of the aircraft structure could be analyzed at subsystem level (e.g., wing, forward fuselage). Some complex items may also warrant analysis at a lower level. For example, a canopy may be identified as a subassembly of the forward fuselage in the hardware breakdown, but may warrant separate analysis due to the number of distinct functions it has which are clearly apart from the fuselage. Information regarding hardware analysis levels must be identified and documented in the Ground Rules and Assumptions section of the RCM Program Plan.

2.4.4 Hardware Selection

Hardware selection is the determination of which hardware items in the hardware breakdown will be analyzed. If a complete analysis will be performed, hardware selection is simply identifying all of the items at the selected level of analysis, minus any items that do not warrant analysis. When considering excluding hardware items from a complete analysis, extreme care and conservative judgment should be used to ensure that no items with a significant impact on safety, environmental compliance, operations, or cost are excluded.

Selecting hardware for a limited scope of analysis will require more consideration. It will be based on the item characteristics and analysis objectives. A limited analysis may be implemented to improve maintenance effectiveness on individual hardware items. For example, analysis may be applied to a number of cost or readiness drivers. In this case, the hardware selected would be those cost or readiness drivers, or higher-level items that contain them depending on the selected level of analysis. Another objective of a limited analysis may be to evaluate current PM requirements. In this case, only hardware items with current PM requirements may be selected. Be aware, in this case, that if all items have not previously been subjected to RCM analysis, the current PM tasks may not be adequate to provide the desired level of safety, environmental compliance, economic, and operational effectiveness for the end item. A limited analysis may also be implemented to evaluate the insertion of new inspection/detection methods for specific hardware items. For a given RCM program, hardware may be selected for any combination of reasons. For any limited analysis, the RCM sustaining program should be established to monitor the performance of the system or end item to identify areas of concern that may not have been subjected to RCM analysis. Regardless of the scope of the initial analysis, an effective RCM program will be sustained such that any additions or changes to the PM requirements will be developed from the results of an RCM analysis. Information regarding hardware selection must be identified and documented in the Ground Rules and Assumptions section of the RCM Program Plan.

2.4.5 Extent of Analysis

The extent of analysis is the determination of how much analysis will be performed on each selected hardware item. This is usually accomplished by determining the failure modes or types of failure modes that will be identified and analyzed through RCM analysis. In a complete analysis, all reasonably likely failure modes should be evaluated. The term “reasonably likely” is included to ensure that only those failure modes that meet some established probability of occurrence are included. This is typically accomplished using a system safety hazard severity matrix. This failure mode prioritization may exclude failure modes from the RCM analysis based on their severity and occurrence.

Like the hardware selection process, the extent to which a limited analysis is conducted depends on the item’s characteristics and analysis objectives. If the purpose of a limited analysis is to improve the reliability of an item to reduce cost or increase readiness, the analysis can be limited to the failure modes that are responsible for the high cost or readiness impact. If the objective of the analysis is to review current PM tasks for effectiveness, it may be limited to the failure modes at which the tasks are directed. In any analysis where all failure modes are not analyzed, the best approach is to identify all "reasonably likely" failure modes, but withhold completion of the analysis for those failure modes not selected until resources or priorities dictate. If all "reasonably likely" failure modes are not identified, this should be clearly noted in the analysis, and program managers should be well aware that the PM program might not be optimized for all failure modes. Information regarding the extent of analysis required must be identified and documented in the Ground Rules and Assumptions section of the RCM Program Plan.

When determining the extent to which an analysis should be taken, it is often useful to define sources of failure mode information, such as the following:

- Failure modes protected by current PM tasks (e.g., Maintenance Requirement Card (MRC) decks and Depot Level Maintenance specifications)
- Failure modes that have not occurred, but are reasonably likely to occur based on the collective experience and judgement of the analysis team (to include input from operators and maintainers).
- Organizational (O) and Intermediate (I) level failure modes from defect reports (engineering investigations, hazardous material reports, bulletins, and mishap reports)
- Depot (D) level in-service failure modes (e.g., temporary engineering instructions, local engineering specifications, and examination and evaluation reports)
- O and I level failure modes from maintenance databases (e.g., NALCOMIS or CMMS data)
- Failure modes identified in corrosion prone areas
- Anecdotal failure modes from interviews with operators and maintainers
- High visibility failure modes (e.g., failure modes causing high cost or readiness issues)
- Test result failure modes (e.g., failure modes from fatigue tests, component certification)
- Failure modes that may benefit from new inspection and detection technology
- Safety and safety hidden failure modes identified in schematic, block and reliability diagrams
- Failure modes of protective or sensing/detective systems and functions that may not be evident without inspections or checks
- Failure modes from failure mode libraries on common equipment types

2.5 GROUND RULES AND ASSUMPTIONS

The Ground Rules and Assumptions are a compilation of specific data and information contained in the RCM Program Plan that is considered necessary for conducting RCM analyses. It includes:

- Description of operating environment (operating context)
- Standard operating procedures
- Data sources
- Analytical methods
- Cost-benefit analysis methods
- Analysis approaches to specific types of problems
- Default values (e.g., labor rates, equipment usage rates, common material costs)
- Acceptable probabilities of failure for system safety failure modes, and

- Any other information that may be required to produce consistent and efficient analyses.

2.5.1 General Considerations

Considerations for inclusion in the Ground Rules and Assumptions are outlined below:

- Analysis thresholds (e.g., cost, failure rates, acceptable risks)
- Level of analysis
- Hardware partitions (including hierarchy and boundaries)
- Analysis approach for interface items such as wiring and tubing
- Analysis approach for repairs and unique configurations
- Methods for dealing with "directed" maintenance tasks (i.e., some PM tasks may be "directed" by higher authority, such as maintenance tasks or intervals prescribed by general series manuals or command instructions, but not supported by RCM analysis. Efforts should be made to resolve these conflicts prior to implementing a task not supported via the RCM process and documented within the applicable analysis.)
- Process for addressing items that have a different cognizant engineering activity (such as items used on several platforms)
- Methods for prioritizing analysis of failure modes
- Defined values for parameters such as labor rates, utilization rates, design life, remaining program life, acceptable probabilities of failure, conversion factors, minimum detectable flaw sizes, and cost information
- Sources for defining item nomenclature (e.g., illustrated parts breakdown manuals, maintenance instruction manuals, drawings)
- What constitutes “normal duties” for the operator? (e.g., duties such as those found in Naval Air Training and Operating Procedures (NATOPS) checklists)
- Procedures for forwarding “Other Action” recommendations from the RCM analysis to appropriate organizational elements
- Procedures for consideration of advanced inspection/detection techniques such as PHM or NDI
- Procedures for documenting supporting information used during the analysis

2.5.2 Failure Modes, Effects, and Criticality Analysis (FMECA)

- Function identification data sources and methodologies
- Failure mode identification data sources and methodologies
- Mission or usage phases or profiles
- Failure detection methods
- Mean time between failure (MTBF) data sources and calculation methodologies

- Deviations from, clarifications to, or tailoring of current failure mode and effects analyses guidance documents
- Severity classification list
- Methods for determining criticality (e.g., Risk Hazard Matrix)

2.5.3 Task Analysis

- Data sources and methodologies for calculating task intervals
- Data sources and methodologies for identifying potential to functional failure intervals and wear-out ages
- Cost analysis data sources and methodologies
- Processes for determination of "Other Action" RCM recommendations
- Deviations from, clarifications to, or tailoring of current RCM guiding documents

NOTE:
The NAVAIR RCM Steering Committee can provide examples of RCM Program Plans and Ground Rules and Assumptions.

2.6 TRAINING AND CERTIFICATION

Training requirements should be defined in the RCM Program Plan. RCM analyses must be performed by properly trained, experienced, and certified personnel to ensure that it is accomplished properly, and that the results can be accepted with confidence. Training should be viewed as an ongoing effort throughout the life of the RCM program, encompassing formal courses as well as on-the-job experience. Training should focus, first, on educating team members to the theory of RCM, followed by its application to real world situations. RCM analysts may acquire the requisite theory from training courses, but it is only after applying that knowledge to real world situations that they become effective team members. All personnel providing significant support to the RCM process should have knowledge and training in the basic RCM concepts.

A period of mentoring is necessary to help analysts, tasked with conducting or leading an analysis effort, transform their theoretical knowledge to the practical skills. During this time, the RCM Implementation Manager or other experienced RCM analyst must provide guidance. The mentor must be closely involved with the work being performed by new analysts, giving feedback and direction as required. As the analyst becomes self-sufficient and proficient in performing the tasks, the mentor's direct involvement diminishes.

An increasingly widespread use of various statistical methods in a broadening range of disciplines has generated a number of courses that focus on particular analysis techniques used to conduct RCM analyses. These courses offer analysts ways to broaden their understanding and further develop the skills needed.

All RCM program personnel should make every effort to keep up to date and informed of new RCM developments, whether they are derived from Government sources or commercial enterprises. Additionally, the RCM Implementation Manager should identify any training requirements that arise from new RCM developments and inform the appropriate Competency that the training is needed for team members.

2.6.1 NAVAIR RCM Training Courses

The RCM training provided by NAVAIR is tailored to several levels of knowledge and experience.

2.6.1.1 RCM Management Overview, Orientation, and Fundamentals Courses

The RCM Management Brief is normally a two to four hour overview of the RCM process, its benefits, and programmatic considerations. It provides a top-level view of RCM and, as such, it is intended for Program Managers, APML's, APMS&E's, FST leaders, and others who oversee or interface with the development and implementation of an RCM program. It provides a succinct view of RCM and its benefits to the Naval Aviation Community.

RCM Orientation is a minimum requirement for RCM Team members who may not be directly executing the analysis process, but interface or provide support in distinct areas. For example, engineers providing technical support, or maintenance personnel providing historical data may require an Orientation Brief to familiarize them with the RCM process, plans and goals. The Orientation may be accomplished using the Management Overview materials, along with additional information specifically related to the project assigned.

The RCM Fundamentals Course is a three-day offering that gives an initial view of such topics as the RCM philosophy, history, and goals. It introduces students to the basic analysis concepts and terminology that are unique to RCM. The course includes a series of lectures, small-group exercises, and a workshop that provide students with an opportunity to apply their newly learned theory to actual analysis problems. Participants are encouraged to share their knowledge of RCM and relate prior experiences with fellow students. The Integrated Reliability-Centered Maintenance System (IRCMS) software, which most NAVAIR RCM programs will use to document their RCM analyses, is also taught during this course. The course provides an excellent foundation upon which analysts can continue to build their expertise through on-the-job RCM training and experience.

2.6.1.2 Propulsion and Power Course Offering

NAVAIR's Propulsion and Power (P&P) community offers a three-day course that introduces the unique aspects of applying an RCM program to P&P items. The course provides a P&P-tailored overview of the various maintenance philosophies, a P&P-oriented RCM program, and the system safety program and its role in RCM. An in-depth discussion is also provided on failure modes, failure distribution curves, and failure intervals. Various methods for establishing RCM metrics, calculating failure distribution curves, and calculating failure intervals recommended for P&P RCM analysis are covered. The last part of the course is an exercise in performing RCM analysis using the information and methods provided in the course.

2.6.2 Data Analysis Training

Statistical methods can be used to plot failure distributions, determine probabilities of failure at a given time in the life cycle, and identify optimal task intervals based on safety or economic concerns. Courses are available in basic statistics, Weibull analysis, probabilistic methods, and other analytical techniques from various sources. The RCM Implementation Manager should be well versed in statistical analysis, and ensure that the RCM analysts can use the appropriate methods when required.

2.6.3 Other Training Topics

The Air Vehicle Structures Competency offers a 10-day course in fatigue and fracture analysis methods and criteria that are applicable to RCM analysis of structural components. Aircraft structural design and certification criteria are reviewed as well.

Courses in fracture mechanics and fatigue and wear characteristics can aid the RCM analyst in determining things such as the PF interval. These courses give the student an indication of what can be looked for in an inspection, as well as how to determine the rate of degradation of an item.

NDI is used to find cracks and other flaws that are too small to be spotted visually, or are otherwise hidden from view. An NDI course should be considered when the RCM analyst needs this background to determine the efficacy of various NDI inspections (eddy current, dye penetrant, etc.) as part of On Condition task development.

Prognostics and Health Management (PHM) Systems technology is relatively new. Specific training and access to experts in this field may be necessary for the RCM program to take advantage of the benefits offered by these systems. Systems or equipment not designed with PHM capabilities in mind may still be able to take advantage of PHM technology through cost-effective design changes or use of monitoring techniques using currently available sensors or performance data.

Since RCM is a team effort, training in project management, team building, effective team operations, presentation and communication skills is beneficial.

2.6.4 Certification

The NAVAIR RCM Steering Committee manages the RCM certification program to ensure appropriately qualified individuals accomplish RCM efforts. The Steering Committee, under the authority of NAVAIR 6.7, designates Site Coordinators to manage the certification of individuals performing RCM at each site.

2.6.4.1 Analyst Certification

There are three levels of certification with Level I being the introductory level. Individual certification nominations (organic and contractor) shall be submitted to the RCM National Lead, Site Coordinator, or RCM Program Lead for consideration for all levels of certification. Proficiency for the intended level of certification shall be demonstrated at the discretion of the Site Coordinator. Final certification shall be granted by the Site Coordinator or the RCM National Lead.

2.6.4.1.1 Level I Analyst (Apprentice) Certification Requirements

Level I certification identifies an analyst as having a basic understanding of the NAVAIR RCM process and this manual. A Level I analyst is considered an apprentice and shall conduct all RCM analysis in conjunction with a Level II analyst or higher.

Level I Certification Requirements:

- Successful completion of the NAVAIR Fundamentals of RCM Analysis Course
- Basic understanding of the Guidelines for Naval Aviation Reliability-Centered Maintenance Process NAVAIR 00-25-403.

Desired Knowledge or Experience:

- Bachelors degree in a technical field or relevant experience related to maintenance, reliability, or safety of NAVAIR systems

2.6.4.1.2 Level II Analyst (Journeyman) Certification Requirements

Level II certification identifies an analyst who has a comprehensive understanding of the NAVAIR RCM process and can perform analyses independently. They have detailed knowledge and understanding of the NAVAIR 00-25-403 manual and the Society of Automotive Engineers (SAE) JA1011 Standard. Level II certification also identifies an analyst as capable of explaining and defending the results of any analyses that they have performed, and identifies them as capable of mentoring Level I analysts. A Level II is a working level analyst and requires analysis approval from a Level III certified approver.

Level II Certification Requirements:

- Minimum of one continuous year of experience as a NAVAIR Level I certified analyst performing RCM analysis.
- Minimum of two years experience related to NAVAIR maintenance, reliability and safety
- Successful demonstration of the performance and knowledge of the RCM process.
- Successful demonstration of a working knowledge of the following:
    - NAVAIR 00-25-403
    - SAE JA1011
    - NAVAIRINST 4790.20 Series

Desired Additional Knowledge or Experience:

- Statistical Analysis Methods
- Reliability Analysis Methods
- System Safety Methods
- Non-Destructive Inspection Methods
- NAVAIR maintenance Data Systems
- Design Interface & Maintenance Planning
- NAVAIR technical publications processes

2.6.4.1.3 Level III Analyst (Senior Analyst) Certification Requirements

Level III certification identifies an analyst who is well versed in the NAVAIR RCM process and capable of leading and mentoring a Level I or II analyst. It also identifies them as capable of planning and leading an overall RCM program effort and developing an RCM Program Plan. A Level III analyst shall have comprehensive knowledge of all aspects of the NAVAIR RCM process and policy, and may serve as an RCM implementation manager or perform extensive RCM analysis. A Level III analyst is a senior level analyst and possesses analysis approval authority as defined in the applicable RCM Program Plan.

Level III Certification Requirements:

- Minimum of one continuous year experience as a NAVAIR Level II certified analyst
- Minimum of three years experience related to NAVAIR maintenance, reliability and safety
- Successful demonstration of the understanding of complex RCM principles and project management skills.
- Knowledge of RCM-related tools and concepts, such as:
    - Weibull Analysis
    - Approaches to RCM analysis of newly designed systems or components
    - Analysis concepts with little or no failure data

Desired Additional Knowledge or Experience:

- NAVAIR Management RCM Overview Brief
- NAVAIR Budget Methods
- Program Management Methods
- Business Case Analysis Methods
- NAVAIRINST 4790.33 series
- Logistics Support methods (elements and implementation)
- Automated Diagnostic Technologies
- Integrated Maintenance Concept
- 13023.2 Series
- Knowledge and experience in project management
- Knowledge and experience with the NAVAIR budgeting and acquisition processes

<u>2.6.4.2 Recertification</u>

Recertification of an RCM analyst to Level I, II, or III is defined as submittal of a new Nomination Form, subject to the applicable certification criteria referenced above. Recertification is required when a period of 18 months has passed without performing RCM analysis. Requirements can be waived on a case by case basis by the Site Coordinator. Recertification is not required with continuous performance of RCM.

Recertification is not required for the following conditions, but certification records shall be updated when:

- A NAVAIR organic employee or contractor moves between programs within NAVAIR
- A NAVAIR organic employee moves between NAVAIR and a contracted company
- A contractor moves to a NAVAIR employed position

2.6.4.3 Special Circumstances for the Approval of RCM Analyses

There may circumstances where RCM programs require analysis and there is no Level III certified analyst available (an example is when a Level III analyst leaves their position on short notice). In this circumstance, the program shall request temporary deviation of Level III approval authority from the Steering Committee. The program shall provide the Steering Committee with a plan to rectify the situation, which shall include the name of a Level II certified organic analyst, the role of the RCM Site Coordinator, and details for managing the progression of the intended analyst to a Level III certification within a one year period. At no time shall the extent of temporary approval authority exceed a one year period (the minimum time required to obtain a Level III certification).

2.6.4.4 RCM Implementation Manager

RCM Implementation Managers are Level III Certified RCM Analysts who are designated by individual programs to manage the performance of RCM for that program, in accordance with the applicable RCM Program Plan. They are also responsible for the submission of nominations of NAVAIR RCM certifications to the RCM Site Coordinators.

2.6.4.5 RCM Site Coordinator

The RCM Site Coordinator manages NAVAIR RCM certifications for their site, provides input on local RCM program status to the RCM National Lead, and is a member of the RCM Steering Committee. The Site Coordinator is designated by the NAVAIR RCM Steering Committee in conjunction with the local Logistics Group Site Leader and is issued a letter of designation by AIR 6.7.1 outlining their responsibilities. This individual is considered an RCM Subject Matter Expert (SME), and is Level III Certified. Figure 2-3 shows the certification hierarchy for NAVAIR RCM.

2.6.4.6 RCM Trainer

An RCM Trainer is an individual certified to teach the NAVAIR Fundamentals of RCM Analysis course. RCM trainers should meet Level II Journeyman Analyst requirements as a minimum, and should additionally be knowledgeable in training methods, have good presentation skills, and should be mentored in at least two classes before leading a training course independently. The NAVAIR RCM Steering Committee Chairman will certify NAVAIR RCM trainers.

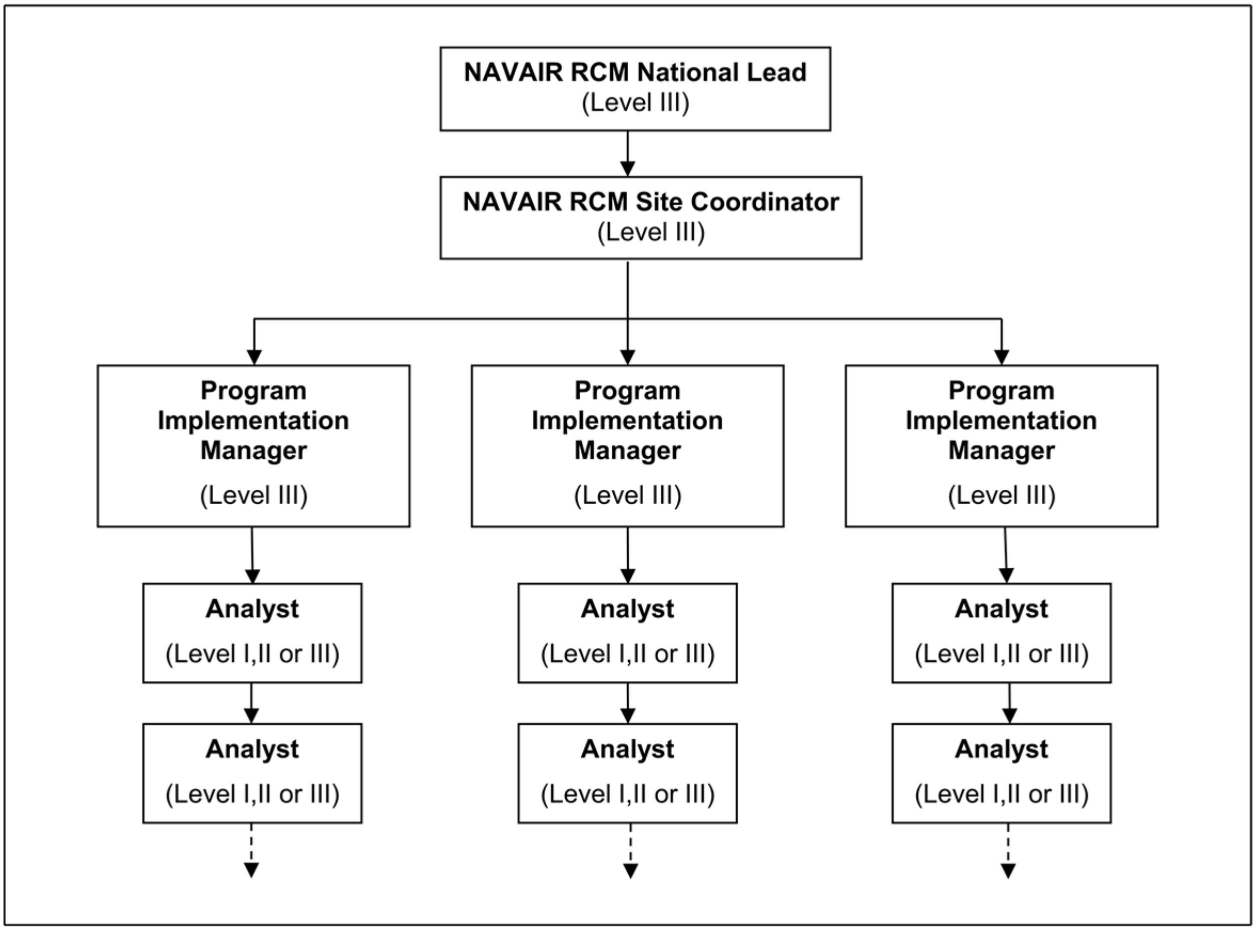


Figure 2-3 RCM Certification Hierarchy

2.7 RCM PROGRAM REPORTING

Providing the status of RCM-related efforts and accomplishments is important to the RCM Program. The RCM Program Plan should define the reports to be compiled and submitted on a periodic basis to the FST Leader, APML, PMA, and other designated recipients. These reports may include, but are not limited to:

- RCM Scorecard – Summary of program RCM actions and metrics, described below
- RCM Status - Summary of RCM analyses performed during the reporting period
- RCM Cost Avoidance - Summary of cost avoidance calculations associated with the RCM analyses performed
- AE Status - Summary of AE inspections, data collected and analyzed during the reporting period, and the resulting changes to the RCM analysis or the maintenance program
- Effectiveness metrics - Metrics reflecting maintenance program performance during the reporting period
- Resource Status - Summary of resource expenditures against planned requirements

The NAVAIR RCM Scorecard is one specific report that is used by FSTs, PMAs, and NAVAIR headquarters. The scorecard tracks metrics such as funding, expenditures, manpower, failure modes (by Severity Classification and Hazard Risk Index), and safety, operational, and economic impacts of RCM implementation and sustainment activities. The scorecard supports and prioritizes resource allocation, tracks RCM program activity, and identifies trends and emergent issues. Each NAVAIR RCM Program shall provide an updated RCM Scorecard to the RCM National Lead no later than 30 calendar days after the end of each FY quarter.

If RCM efforts are contracted, appropriate contract data deliverable list (CDRL) items or other deliverable products need to be specified in the contract SOW.

2.8 FUNDING REQUIREMENTS

Funding requirements for implementing an RCM program may be divided into two parts, the initial analysis effort and the sustaining effort.

Funding requirements should be consistent with the RCM plan. Consider, for example, the following when estimating funding requirements:

- Number of items, functions, and failure modes to be analyzed along with their complexity
- Potential benefits to be gained by improvements to the maintenance programs and the equipment to be analyzed
- Depth of the analysis to be conducted
- Scope of analysis
- Data availability
- Experience base of the RCM Team
- Level of certification/experience and availability of analysts who will lead/conduct the analysis efforts
- Timeframe for accomplishing the effort
- Status or condition of the FMECA
- Contractor versus organic effort
- In-service versus new program

Consideration should be given to the availability and stability of the funding, which may cause changes in analysis scope, timeframe, and other elements of the program.

Funding requirements for the initial analysis will be driven, largely, by the scope of analysis, as described in Section 2.5. When establishing the funding requirements for a given RCM program plan, it may be beneficial to draw information from programs that have conducted similar analyses. The NAVAIR RCM Steering Committee may also be consulted to aid in this effort.

2.9 DATA SOURCES

Several data sources are useful for RCM purposes. Sources range from fleet maintenance data systems to specific engineering data that are available in the form of design reports, test result reports, and engineering investigation reports. The RCM program plan should identify data sources to be used in the analysis. The Ground Rules and Assumptions section of the RCM plan is used to describe how various data sources can be used to support the different types of analyses that will be encountered during the RCM process.

The RCM Program Plan should be used to identify special data that require additional efforts or resources to obtain. Examples of special data include manufacturer's proprietary data, production inspection records, vendor's overhaul and rework data, test reports, engineering studies, drawings, and computer modeling.

2.10 RCM PROGRAM METRICS

It is generally accepted that implementation of an RCM program increases the efficiency of a maintenance program. However, quantification of the improvement is necessary to evaluate its success. The RCM program must establish metrics in order to make meaningful assessments. When performing an assessment, care must be taken to attribute only those successes and failures that are directly related to the RCM process.

Established reporting methods are in place for making general assessments of effectiveness of RCM programs for most in-service equipment. These should be described or established in the RCM Plan. These include parameters such as availability, readiness, Mean Time Between Failures (MTBF), Total Ownership Cost (TOC), Direct Maintenance Man-hours per Flight Hour (DMMH/FH), and Mean Time Between Removal (MTBR).

2.11 IMPLEMENTATION OF RESULTS

A completed initial RCM analysis will produce a number of recommendations. These include recommendations to allow certain items to operate to failure; recommendations to take some Other Action when warranted (e.g., redesigning items, changing operational or maintenance procedures); and recommendations to implement a variety of PM tasks. Methods for review, approval, and implementation of results should be described in the RCM Plan. Program managers responsible for the items analyzed should be apprised of results, impacts, and benefits prior to implementation.

The process of implementing the results from the RCM analysis fall into two general areas: 1) packaging and incorporating the recommended PM tasks into a preventive maintenance program, and 2) taking steps to address "Other Action Warranted" recommendations. Thought should be given during the planning process as to how these two issues will be addressed.

Each PM task recommendation will have a discrete engineering task interval associated with it. These PM task recommendations must be converted to a coherent maintenance program that produces effective and efficient results. While packaging intervals should not be determined until after all of the analyses are complete, the processes and techniques used to develop the packaged intervals should be identified during the RCM program planning process. Section 4 provides information on packaging processes. Once packaged, the support requirements for the PM tasks must be determined via the maintenance planning process.

Implementation of Other Action Warranted recommendations must be addressed during the RCM program planning process. Most, if not all, Other Action Warranted tasks have specific processes that require attention that falls outside the purview of the RCM program. For example, design changes require implementation through the Engineering Change Proposal process. Any external processes that can be foreseen as possibly requiring RCM analysis data should be addressed during the RCM program planning process and identified in the RCM program plan. Section 4 of this manual provides additional information regarding the implementation of “Other Action” recommendations that result from RCM analyses.

2.12 RCM PROGRAM SUSTAINMENT EFFORTS

To realize the full benefit of RCM, sustainment of an RCM program after completion of the initial analysis is critical. A one-time analysis will not provide an optimized PM program that can be expected to extend over the life of a hardware program. There are two reasons for this. First, the initial analysis will never be optimized since, in all likelihood, incomplete and inaccurate data and assumptions were used in the decision-making process due to a lack of solid data. The second reason is that the hardware and its operating environment will likely change over time.

An initial analysis is based on the best information available at the time. However, no matter how much data is collected, or how well it is screened and evaluated, some of it will, over time, prove to be inaccurate or incomplete. The initial analysis will also be based on many assumptions, some of which will prove to have been inaccurate. Other assumptions, which were true initially, will become invalid as the hardware progresses through the various stages of its lifecycle.

In addition to the analysis becoming out-dated by changing data and assumptions, the hardware and its operating environment will likely change over time. Hardware will be physically modified to improve performance or to perform entirely new functions. New demands may be placed on equipment. Users may operate equipment differently or in different environments. Unless new equipment is continuously being procured, the average age of a population of equipment will increase. Finally, maintenance practices and available technology may change.

Due to the factors mentioned above, RCM analyses must be updated to address any changes that affect the PM program. These updates should be accomplished as changes occur. The RCM sustainment process should be thoroughly defined in a program’s RCM Program Plan to include:

- Funding requirements
- Data requirements
- Training requirements
- FST organization, responsibilities, and procedures related to the RCM program

Section 5 of this manual provides detailed descriptions of the types of tasks that are necessary to properly sustain an RCM program.

2.13 RCM CONSIDERATIONS IN A PBL ENVIRONMENT

Performance Based Logistics (PBL) is a strategy for system support. The objective is for the Government to contract for a guaranteed level of performance of a system, rather than specific goods and services. Level of performance objectives can be tracked using metrics such as: (1) Operational Availability, (2) Operational Reliability, (3) Cost per unit usage, (4) logistics footprint, and (5) logistics response time. RCM programs should track metrics that can be related to the metrics and objectives set forth in the PBL contract. This is done in order to assess the impacts and effectiveness of an RCM based failure management strategy. In a PBL environment, RCM may not be directly driven in a contract. However it should be recognized as a “best practice” in developing preventive maintenance requirements.

2.14 RELATIONSHIP OF RCM TO CBM+

Condition Based Maintenance Plus (CBM+) is the primary reliability driver in the total life-cycle systems management (TLCSM) supportability strategy of the Department of Defense. CBM+ encompasses the application of RCM along with other technologies and processes. CBM+ is a comprehensive strategy to select, integrate, and focus a number of process improvement strategies and diagnostic/machine health sensing capabilities, thereby enabling maintenance managers and their customers to attain the desired levels of system and equipment readiness in the most cost-effective manner.

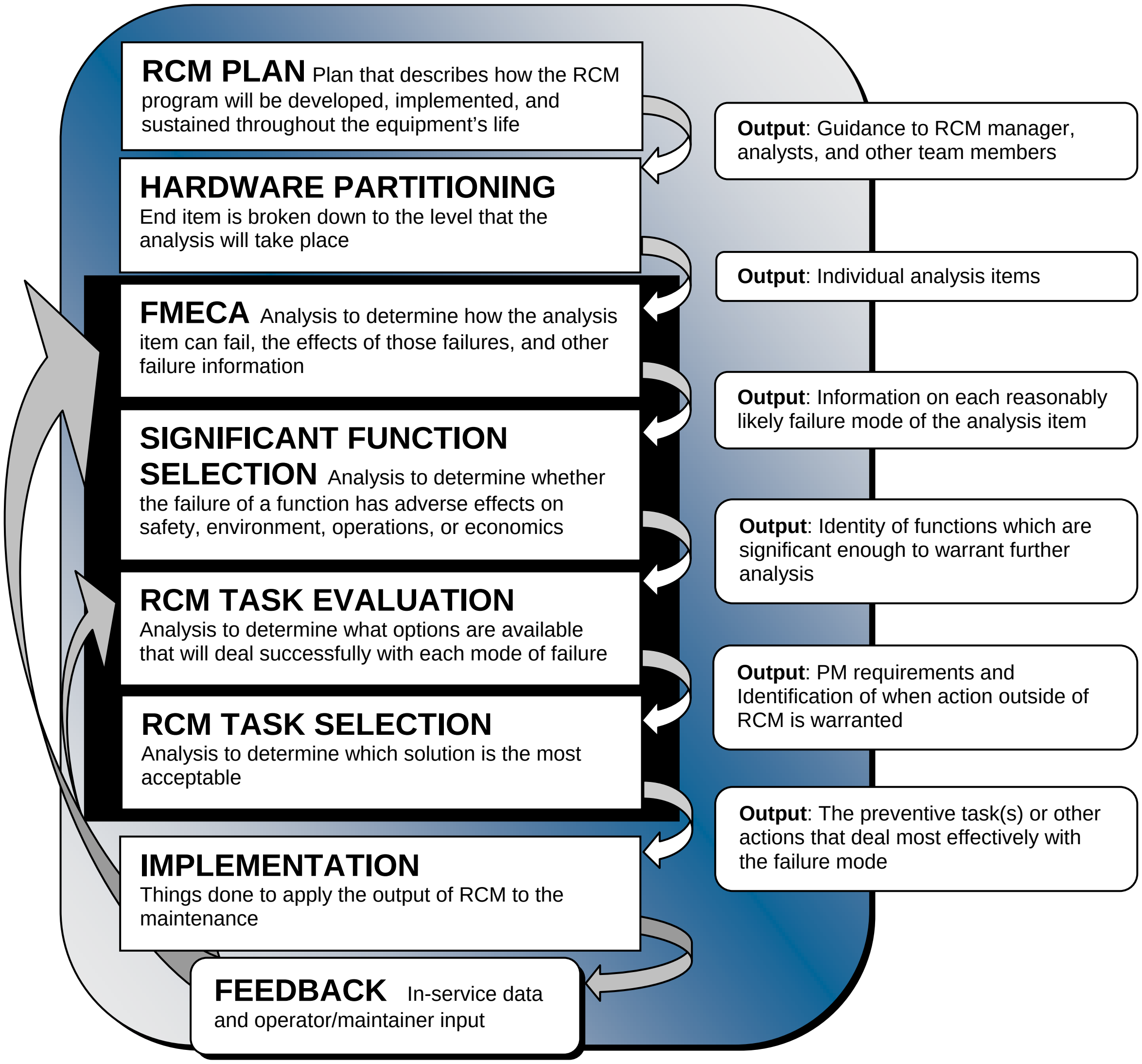
There is a close relationship between RCM and CBM+. RCM provides the evidence of need for other CBM+ processes and technologies such as health monitoring or prognostics. RCM provides an understanding of the applicability and effectiveness of proposed CBM+ technologies as well as an analysis of other alternatives. Guidance for CBM+ and RCM has been established in DoDI 4151.22 Condition Based Maintenance Plus (CBM+) for Materiel Readiness. Additional CBM+ information is located in the CBM+ DoD Guidebook.

SECTION III

RCM ANALYSIS PROCESS

3.1 INTRODUCTION

This section describes the RCM analysis process. The RCM analysis process (highlighted in black in Figure 3-1) includes performing a Failure Mode, Effects, and Criticality Analysis (FMECA), selecting significant functions, and performing task evaluations and task selections. Figure 3-1 also illustrates where the RCM analysis process fits in the overall RCM program.



RCM PLAN Plan that describes how the RCM program will be developed, implemented, and sustained throughout the equipment's life

HARDWARE PARTITIONING End item is broken down to the level that the analysis will take place

FMECA Analysis to determine how the analysis item can fail, the effects of those failures, and other failure information

SIGNIFICANT FUNCTION SELECTION Analysis to determine whether the failure of a function has adverse effects on safety, environment, operations, or economics

RCM TASK EVALUATION Analysis to determine what options are available that will deal successfully with each mode of failure

RCM TASK SELECTION Analysis to determine which solution is the most acceptable

IMPLEMENTATION Things done to apply the output of RCM to the maintenance

FEEDBACK In-service data and operator/maintainer input

Output: Guidance to RCM manager, analysts, and other team members

Output: Individual analysis items

Output: Information on each reasonably likely failure mode of the analysis item

Output: Identity of functions which are significant enough to warrant further analysis

Output: PM requirements and Identification of when action outside of RCM is warranted

Output: The preventive task(s) or other actions that deal most effectively with the failure mode

Figure 3-1 RCM Process

3.2 FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS

The FMECA is a process used to identify and document the functions, functional failures, failure modes and failure effects of an item. It is used to determine the significance of functional failures in terms of Safety, Environment, Operations, and Economics. It further classifies the severity of each failure effect according to established severity classification criteria, and provides failure rate information.

The FMECA starts with a hardware partition as described in section 2.4.2. The partition shows the relationship of each item to other items and to higher or lower levels of indenture.

It is important that, prior to beginning the development of the FMECA, the ground rules and assumptions discussed in section 2.5.2 are established and well understood. It is essential that the mission or usage phases and profiles be described in the RCM Plan so that the FMECA is developed based on a well-defined operational context. It may be that some functions, failures or effects only occur, or occur in a different manner, in certain operational scenarios. The FMECA should clearly indicate when functions, failure modes or effects are dependent on specific circumstances, environments, or mission phases.

3.2.1 Function

A function is the intended purpose of an item as described by a required standard of performance. It is not necessarily what the item is capable of doing, as shown in the example below. A complete function description should include any specific performance limits (upper and/or lower bounds).

Example of a Function Description

A particular application requires a hydraulic pump that is capable of providing 3000 psi +/-200 psi. A hydraulic pump that is rated for 4000 psi is chosen for the application. A proper function description would be:

> “Provide hydraulic pressure of 3000 psi +/-200 psi”

Although most equipment is designed to perform a specific or single function, many systems may perform multiple functions or have secondary functions. Some functions are "demand" driven, such as an ejection seat, while others operate continuously. Care must be taken to ensure functions are not overlooked, and that the function statement is clear, including any operating context notations.

An example of an item with multiple functions is an aircraft landing gear system. It supports the aircraft ground load. It retracts when the aircraft is airborne. It extends when the aircraft is airborne, prior to landing.

Examples of secondary functions for the landing gear system include the following:

- Provide fluid containment
- Provide protection from environment damage or exposure
- Provide warning indicators

- Provide steering control for the aircraft
- Provide safety or protective features to prevent injury to personnel during ground maintenance
- Transfer structural loads to appropriate points of the airframe

Virtually all systems have primary and secondary functions. Secondary functions are often less obvious than the primary function, but may have more severe consequences if they fail. Secondary functions to consider for the system under analysis include:

- Fluid Containment
- Environmental protection (paint, sealants, covers, etc.)
- Indications (visual, audible, tactile)
- Controlling features
- Safety or protective features (for the equipment, the operators, the maintainers, or sometimes, bystanders)
- Transfer of loads or back-up load capability
- Aesthetics and comfort

Functions should not be combined if failure consequences are different for each function. For example, two functions of an aircraft landing gear system are to “extend landing gear” and to “retract landing gear.” There may be a tendency to create one function "extends and retracts landing gear". However, if the landing gear fails to extend, the aircraft will not be able to land without significant damage. However, if the landing gear fails to retract, the consequence might be limited to the loss of a mission.

Functions that only apply during certain operational or mission scenarios or context should be clearly noted. These will require special attention in the RCM analysis. Resulting functional failures and failure modes can then be identified such that they clearly relate to the appropriate scenario or context. Reliability and cost values may also require adjustment to account for the usage profiles of the item or function. Information for determining functions can be drawn from several sources such as maintenance and operations manuals, drawings, and discussions with equipment operators, maintainers, and design engineers. Block diagrams for each indenture level being analyzed provide both functional and reliability information. They illustrate the operation and relationships of the functional entities involved in the system’s use.

SAE JA1012 provides additional discussion on the development of function statements.

3.2.2 Functional Failure

A functional failure is defined as the inability of an item to perform a specific function within the specified limits. A functional failure may not necessarily be a complete loss of the function.

Proper functional failure descriptions are based on the function description. Functional failures will likely result in either reduced performance or total loss of the system. Separate functional failures should be listed where the effects of less than total loss of the function are different from total loss.

Information for determining functional failures can be drawn from sources such as maintenance manuals, drawings, and discussions with equipment operators, maintainers, and design engineers. Proper functional failure descriptions include parameters such as upper and lower limits of the failure regime, if different than the function description. SAE JA1012 also provides additional useful discussion of functional failures.

Examples of a Functional Failure Description

The function of a hydraulic pump is to provide 3000 psi +/-200 psi. In this example, it is also known that once the hydraulic pressure drops below 1000 psi a certain critical component ceases to function.

Valid functional failures could be:

Pump provides more than 3200 psi

Pump provides between 1000 psi and 2800 psi

Pump provides less than 1000 psi

Pump provides no pressure

3.2.3 Compensating Provisions

Compensating provisions are design provisions or operator actions that circumvent or mitigate the effect of the functional failure. Compensating provisions may include such things as back-up/redundant functions, safety or relief devices, or crew-selected mitigating actions (such as switching to secondary systems following caution/warning indications). The FMECA should include a detailed description of compensating provisions for each functional failure if they exist. Compensating provisions are used to assist in determining the failure effects, severity, and consequences.

Information for determining compensating provisions can be obtained from sources such as maintenance manuals, operator manuals, drawings, and discussions with equipment operators, maintainers, and design engineers.

3.2.4 Failure Mode

A failure mode is a specific physical condition that can result in a functional failure. The failure mode statement should include a description of the failure mechanism (e.g., fatigue) in addition to the specific condition whenever possible.

A lot of effort could be expended in imagining all the ways something might fail, however, only failure modes that are “reasonable” should be identified. The RCM program plan’s Ground Rules and Assumptions section should list the methods and data sources for identification of “reasonable” failure modes to avoid unnecessary analysis effort for highly improbable failure modes. Failure mode statements should be as descriptive as possible to eliminate confusion over what the failure mode is and where it occurs, to avoid listing redundant failure modes, to readily relate in-service data to the failure mode, and to aid in the development of the appropriate failure management strategy.

Care should be taken when combining disparate failure modes if their rates of occurrence, effects/consequences, or detection methods/probabilities are different, possibly requiring different failure management strategies or PM tasks/intervals. If failure modes are combined due to their similarities, the resultant failure management strategy (including any required PM), must consider the worst case effects/consequences and combined rate of occurrence which may result in an additional maintenance burden that more than offsets any savings in analysis effort.

Refinement of the failure modes and their descriptions may be required as the analysis proceeds. The analyst can choose to add more failure modes or expound on their descriptions, as necessary, to facilitate the identification of specific inspection and failure detection methods. This could be done, for example, when applying the analysis process to PHM. Excessive detail and unnecessary expansion, without clear benefit, should be avoided as this will only serve to add complexity, cost, and delay to the analysis; possibly introduce failure modes not considered "reasonable"; or result in separate failure management strategies or unnecessary maintenance for failure modes that are essentially identical.

The data available for identifying failure modes will vary depending on whether or not the item has an existing service history. Failure modes for items with an existing service history are determined mainly from operators and maintainers and failure data that have been collected. Descriptive failure data sources such as test reports, engineering investigation reports, hazardous material reports, and depot estimator and evaluator write-ups are useful for determining the failure modes of an item. A review of computerized or "coded" data, such as NALCOMIS malfunction codes, is useful to a lesser degree for identifying specific failure modes since, by design, the data is less descriptive. However, this data may be used to identify the types of failure modes seen in-service such as cracks, wear, etc. It may also be used to validate the failure modes developed from other sources as "reasonable", or aid in developing frequencies of occurrence. Maintainers and operators who have first hand experience with the equipment serve as another very useful source of specific failure data.

Failure mode identification on new designs is more difficult. Failure modes have to be inferred from knowledge of the hardware design, general knowledge of how things fail, and experience with similar equipment in similar applications. Data sources will include technical data (publications, drawings) and failure data sources mentioned above for similar equipment in similar usage. The context in which the equipment is operated should be carefully considered when determining the applicability of generic reliability data. Furthermore, data covering the results of fatigue, reliability, developmental, and qualification testing are useful for items with or without a service history.

The following list shows several other sources may be available for identifying failure modes:

- Naval Aviation Maintenance Discrepancy Reporting Program reports

- Aircraft Engine Management System reports
- Parts Life Tracking System reports
- Materials laboratory data and reports
- Failure Reporting and Corrective Action System reports
- Design drawings and maintenance manuals
- Depot artisans, design engineers, fleet support team members, vendors
- Generic reliability data from sources such as MIL-HDBK-217, Reliability Prediction of Electronic Equipment

Examples of a Proper Failure Mode Description

Crack in flange radius due to fatigue.
Leaking actuator due to worn seal.

Example of an Improper Failure Mode Description

Leaking actuator due to worn seal or cracked housing.

3.2.5 Failure Effect

Failure effect is described as the result of a functional failure on surrounding items, the functional capability of the end item, and hazards to personnel and the environment. In other words, it is the impact that a functional failure has on the item under analysis, the surrounding environment (to include equipment and personnel), and the functional capability of the end item. Failure effects should describe any physical damage, including both primary and secondary damage that may occur, and any actions required to restore system function. They should identify the effects on personnel and system safety, the mission, the physical asset(s), and include any unplanned operator or maintainer actions required to restore functional capability. Failure effects should be described as if no PM task is in place to prevent or find the failure.

Examples of Failure Effects Descriptions

Local Effects: Pump leaks hydraulic fluid

Next Higher Effects: Hydraulic System pressure drops below 1000 psi / degraded flight controls

End Effects: Mission abort, pump repair or replacement required

****

Local Effects: Actuator does not provide required output force

Next Higher Effects: Loss of flight control surface function

End Effects: Loss of aircraft/crew

Failure effects are used in the RCM analysis process to determine the consequences of failures so that appropriate PM tasks may be developed. The consequences of failure adversely impact personnel safety, the environment, mission accomplishment, and economics. To determine the consequences of the failure, the analyst must identify the effect that the occurrence of a failure mode has on the end item. An understanding of how the occurrence of failure modes affects each functional level of the hardware is essential for determining their effects on the end item. Often, effects vary under different mission/usage phases or profiles and this must be carefully evaluated and documented. In these cases, it may be necessary to list different effects based on the usage scenario. This information will be used in the RCM process to determine the proper failure management strategy. For example, certain PM or Other Actions may need to occur only while deployed on-board an aircraft carrier. Other systems may be dormant for periods (such as support equipment, missiles, or weapons) and have different failure management strategies while in dormant/storage phase than when active or installed.

Most FMECAs identify three levels of failure effects: local, next higher, end item. Three levels are usually sufficient for most analyses, but they may be added to or eliminated as required.

When applying failure effects to protective devices, monitoring systems, advanced diagnostics and PHM systems, consider the protected function as well as the protective function is in a failed state. Failure effects for emergency functions that are only activated based on the occurrence of a "demand event" should be described considering that the event has occurred and this assumption should be included in the description (e.g., "inability to eject following in-flight emergency leading to loss of life" or "inability to extinguish fire causing loss of aircraft"). Examples may include ejection systems, fire detection systems, or missile "self destruct" systems. These "demand events" should be described in the RCM Plan ground rules and assumptions as a mission or usage phase, and the effects carefully documented as applicable to the appropriate phase.

Sources of information for identifying failure effects include maintenance manuals, defect reports, drawings, contact with maintainers, depot artisans, designers, vendors, and materials laboratories, various test results, and functional block diagrams.

3.2.6 Failure Detection

Failure detection is the means by which functional failures become evident and how their failure modes are identified. Failure detection methods fall into two categories: (1) those that are used by the operator to detect functional failures or the effects of functional failures; and (2) those that are employed by the maintenance technician to determine which failure mode occurred to cause the functional failure.

The methods used by the operator to detect functional failures will vary from failure mode to failure mode due to the different secondary damage that can be caused by each failure mode. Failure detection methods used by the operator include visual warning signals (e.g., lights, gauges), audible warning signals (e.g., horns, buzzers, recorded voice), and operational effects (e.g., vibration, smoke, noise, loss of control). This information is used in the RCM analysis process to determine if the operator can detect the functional failure under normal circumstances and minimize intrusive inspections or maintenance actions where possible.

Failure detection methods that depend on maintenance technicians who use troubleshooting techniques and procedures, are not considered “normal circumstances” when considering operator detection for RCM analysis. However, these methods are important in developing the proper failure management strategy, such as a PM task or Other Action (which could include improved maintenance procedures or equipment). Examples of such failure mode detection methods include pressure tests, voltage checks, visual inspections, NDI, and PHM systems that isolate failure modes automatically. Again, clear description of these methods will aid the RCM analysis in choosing the most appropriate and least intrusive detection method, minimizing induced from the maintenance activity.

Sources of information for identifying failure detection methods include maintenance manuals, operator manuals, drawings, maintainers, operators, depot artisans, designers, vendors, materials laboratories, various test results, and functional block diagrams.

3.2.7 Severity Classifications

Severity classifications are assigned to failure modes based on the impacts of their failure effects at the end item level. Classifying failure modes in this manner provides a primary source for determining the priority under which each should be addressed, and may also be used by the program to establish the acceptable probability level for failure modes based on categories of effects. Historical guidance regarding severity classification has been to review the worst-case effects and assign the Severity Classification on the basis of these effects. While it remains good practice to identify worst-case effects, lesser effects should also be considered and classified, along with their probability of occurrence, for the best understanding of the potential impact of the failure mode. Often the lesser effects occur with such greater frequency than the worst-case effects that they may need to be considered when choosing the best failure management strategy, or assigning an acceptable probability of failure for the failure mode. For example, a failure mode that has a small probability to cause loss of life might have a high probability to create severe operational or economic effects. Determining a failure management strategy to protect against the safety consequences might overlook a better strategy that also optimizes cost or operational impacts. Also, as discussed in section 3.2.5, it may be necessary to assign different classifications for a single failure mode dependent on operational phase or scenario. A description of the severity classification method adopted by the program should be included in the Ground Rules and Assumptions section of the RCM plan.

3.2.8 Mean Time Between Failure (MTBF)

MTBF is a basic measure of reliability and is often defined as the average time a component or system works without failure. Often, the "Time" element in the MTBF used for RCM is replaced by other units appropriate to the failure mode (such as flight hours, operating hours, captive carry hours, or other units with a correlation to the usage/degradation of the item under analysis). Although this appears to be a fairly simple concept, there is tremendous variability in how MTBF’s are determined because they may be used for a multitude of purposes. As a result, it is important to describe how MTBF is used in RCM analysis and to structure its definition accordingly.

In the context of RCM analysis, MTBF is used for 4 purposes:

- To determine the need and frequency for non-safety on-condition tasks
- To determine the need and frequency for failure finding tasks
- To document a relative measure of reliability in the FMECA for use in evaluation of failure management strategies

- To prioritize failure modes that may require analysis.

Prioritization of analysis can use any reasonable method for determination of MTBF as long as the method is consistently applied, but that is not true for the other 3 purposes.

A prerequisite for determining if PM (or other failure management strategy) is desired is to determine how often failures would occur if PM (or other failure management strategy) were not imposed. Therefore, in RCM context, MTBF is defined as the average time (or other appropriate usage parameter) a component or system operates without failure from a particular failure mode, assuming no actions are taken to prevent that failure mode. In other words, MTBF is the average age of an entire population of assets, assuming that those that failed were all run to failure under normal operational conditions, without PM (or other failure management strategy) imposed. This is called the Unmitigated MTBF. As a result, in-service data often cannot be used to directly calculate the MTBF for RCM purposes, because some form of PM may already be in place. In such cases, MTBF values must be estimated based on an understanding of the failure mechanism, its degradation characteristics, and the impacts of the imposed PM (sometimes using data on similar equipment without PM). Therefore, the MTBF values listed in a FMECA should clearly identify the methodologies used, and sources and timeframes for any data used in the calculations.

When MTBF values are calculated from in-service data or vendor/manufacturer data on similar equipment, the values may also need to be adjusted to compensate for differences in equipment design or operational context, in addition to accounting for the influence from existing PM tasks.

Therefore, considerations when using in-service data to calculate MTBF include:

- When using NALCOMIS or CMMS data, failures will often have to be divided among several failure modes since failures may be documented in several ways. For example, they may be documented against a higher level assembly, or they may be documented at different locations on the analyzed item, or they may represent several different failure modes within a given malfunction code. Input from maintainers should be solicited to assign reported failures to the most appropritate failure modes.
- The occurrence of one failure mode may result in a corrective action that, in turn, prevents the occurrence of another failure mode. For example, if an assembly is removed for repair, often the repair process corrects failure modes or restores the item's condition other than for the failure causing it to be removed. Input from repair sites should be obtained to determine failure modes revealed during repair and the MTBF adjusted accordingly.
- In-service data may include the effects of a current or past preventive action. If a current failure mode has a PM task in place, adjustment to the calculated MTBF to account for that PM task is necessary. For example:
  - When an On Condition task is in place, in-service data will include both potential failure and functional failure information. Therefore, the unadjusted MTBF considering both potential and functional failures (influenced by potential failures discovered by the On Condition task) will be lower than the MTBF with no PM task in place.

  - When a Hard Time task is in place, in-service data will not include failures that would have occurred had the Hard Time task not been performed. Therefore, the unadjusted MTBF will be higher than the MTBF with no PM in place.

- Items or functions may be dormant for extended periods of time, therefore any failure modes that occur during the dormant period may not become evident until the item is activated, causing the MTBF to appear longer than actual.

The age distibution of the population, the number of items per end item, and the existence of infant mortality (among other factors) may skew the MTBF requiring careful evaluation and appropriate statistical methods. Also, equipment design, operating environment, maintenance process, and other factors change and may impact failure rates over time. The use of MTBF in the RCM process is to project the average time/usage between functional failure caused by a single type of failure mode on each item without PM. Various methods may be appropriate for making this determination dependant on available data and type of equipment. Various reliability guides and studies may be researched if more precise determination of MTBF or failure rates are desired.

3.3 SIGNIFICANT FUNCTION IDENTIFICATION

A complex system is made up of a vast number of physical parts and components, each of which is designed to perform a specific function or functions. Failure of any of these may cause the loss of function with the added possibility of incurring secondary damage to other system components, personnel, or the surrounding environment. The consequences that these failures have on the end item (aircraft, weapon system, support equipment, engine, etc.) vary over a wide range. The consequences that result from some failures present threats to safety or the environment, while others affect the operating capability of the end item. Other failures result in, and are confined to, economic impacts. Finally, there are those failures that present no significant consequences at all. Functions whose failures result in safety, environmental, operational or economic consequences are termed “Significant Functions” and are subjected to RCM analysis to determine appropriate failure management strategies.

Since every end item contains both “significant” and “non-significant” functions, some method must be employed to segregate them. The following paragraphs discuss the preferred method for identifying significant functions. However, if a program has a method that is different and unique to its application, then that method can be used. In any case, the method selected for use should be described in the RCM program plan.

3.3.1 Significant Function (SF) Logic

The RCM process provides a means through the SF Logic to identify and segregate significant functions and non-significant functions. Figure 3-2, Significant Function Logic Diagram, illustrates the logic used in this process.

- Significant Function (SF) – A function whose failure will result in adverse consequences with respect to Safety, Environment, Operations, and Economics.
- Non-significant Function (NSF) – A function whose failure will have no adverse safety, environmental, operational, or economic consequences.

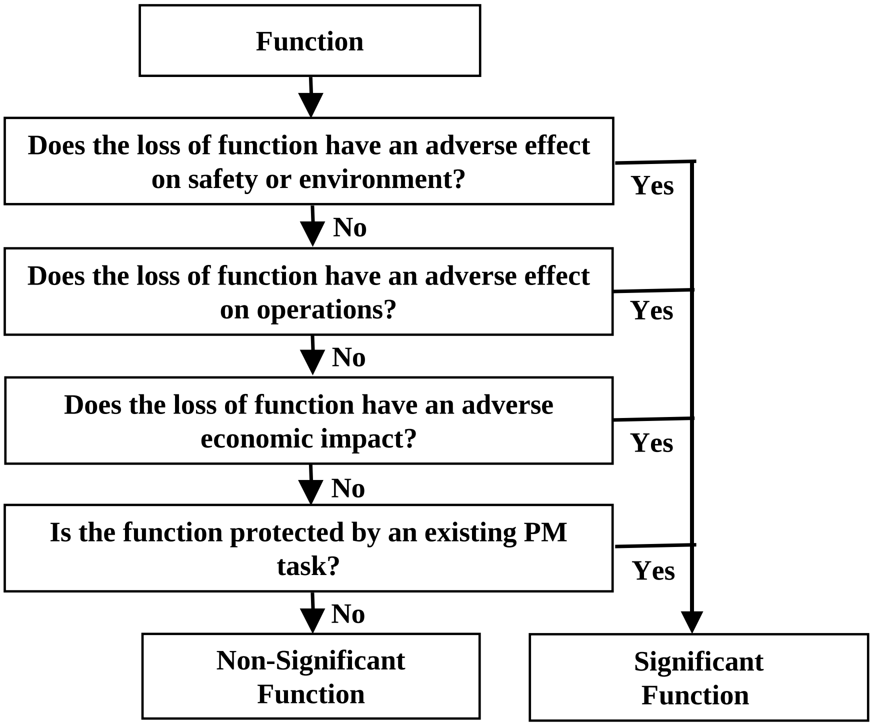


Figure 3-2 Significant Function Selection Logic Diagram

3.3.2 SF Logic Questions

The logic questions asked in the SF Logic diagram apply to every function that has the potential of being significant. It is important to understand that an item may have more than one function. Each function must be evaluated separately. It must be pointed out that the first question in the logic flow that evokes a "YES" answer dictates that the function is significant, thus negating the need to consider the remaining logic questions. If, on the other hand, all of the logic questions evoke a "NO" answer, then the function is considered non-significant, and, therefore, requires no further analysis. While answering any of these questions, consideration must be given to all possible effects of failure modes for the function being analyzed. This includes secondary damage (such as foreign object damage) that may not directly result from the loss of the function. In the case where secondary damage is the only effect that makes a function significant, it may be possible to add a secondary function whose loss results directly in the secondary damage. The effects of losing this function would then be the secondary damage. For example, many hardware components may cause foreign object damage if they become unattached from their attach points. The resulting damage may have nothing to do with the actual system performance of the component or be much more severe than the loss of the subject system. This "secondary damage" could be addressed by adding the secondary function: "Component xyz maintains secure attachment to the airframe."

- Adverse Effect on Safety or Environment? - Does loss of the function or secondary damage caused by a particular failure mode have an adverse effect on operating safety or lead to a serious violation of an environmental standard or regulation? “YES” indicates that the particular function is significant.
- Adverse Effect on Operations? – Does the loss of the function or secondary damage have an adverse effect on operations? “YES” indicates that the particular function is significant.
- Adverse Economic Impact? – Does the loss of the function or secondary damage have an adverse economical impact? “YES” indicates that the particular function is significant.
- Existing PM Task? - Is the function protected by an existing PM task? “YES” indicates that the particular function or secondary damage is significant at this point in the process. Further analysis may determine that the PM task was inappropriately included in the maintenance program. If new hardware is being analyzed, this question may be addressed based on similar items used in similar applications. This effort is simply to identify functions to be analyzed and does not imply that the existing PM task is appropriate or necessary.

The Significant Function Identification process often serves to ensure that all appropriate functions and effects have been included prior to beginning the RCM analysis, vice excluding a large number of functions from consideration. The logic process may reveal existing PM tasks are addressing functions which were overlooked during the development of the FMECA, or it may cause a re-evaluation of the effects. The criteria for eliminating a function from further analysis (no adverse effect on safety, environment, operations, or economics and no existing PM) usually only results in eliminating functions that were somewhat nebulous to begin with.

3.4 RCM DECISION LOGIC

The significant functions that were identified and substantiated by the SF Identification Logic undergo further scrutiny as they are subjected to the RCM Decision Logic. The RCM Decision Logic is used to determine the appropriate failure management strategy to accept, eliminate, or lessen the consequences of functional failures. Every functional failure has one or more failure modes, any of which, if allowed to occur, will result in a loss of function. Each of these failure modes must be processed through the Decision Logic to determine whether a PM task should be developed, or if some other action might be warranted. The goal here is to determine the best alternative for either preventing the functional failure altogether, mitigating its consequences to an acceptable level if it does occur, or allowing it to occur and accepting the consequences.

The Decision Logic requires that the following be considered for each failure mode being analyzed:

- Consequences of failure (safety, environmental, operational, economical)
- Evidence of a functional failure to the operating crews
- Evidence of reduced resistance to failure
- Age-reliability characteristics of each item

- Trade-off analyses comparing various appropriate PM tasks, no PM, or Other Actions for optimum handling of a failure mode

The RCM Decision Logic Diagram, Figure 3-3, and its use will be discussed in the following sections.

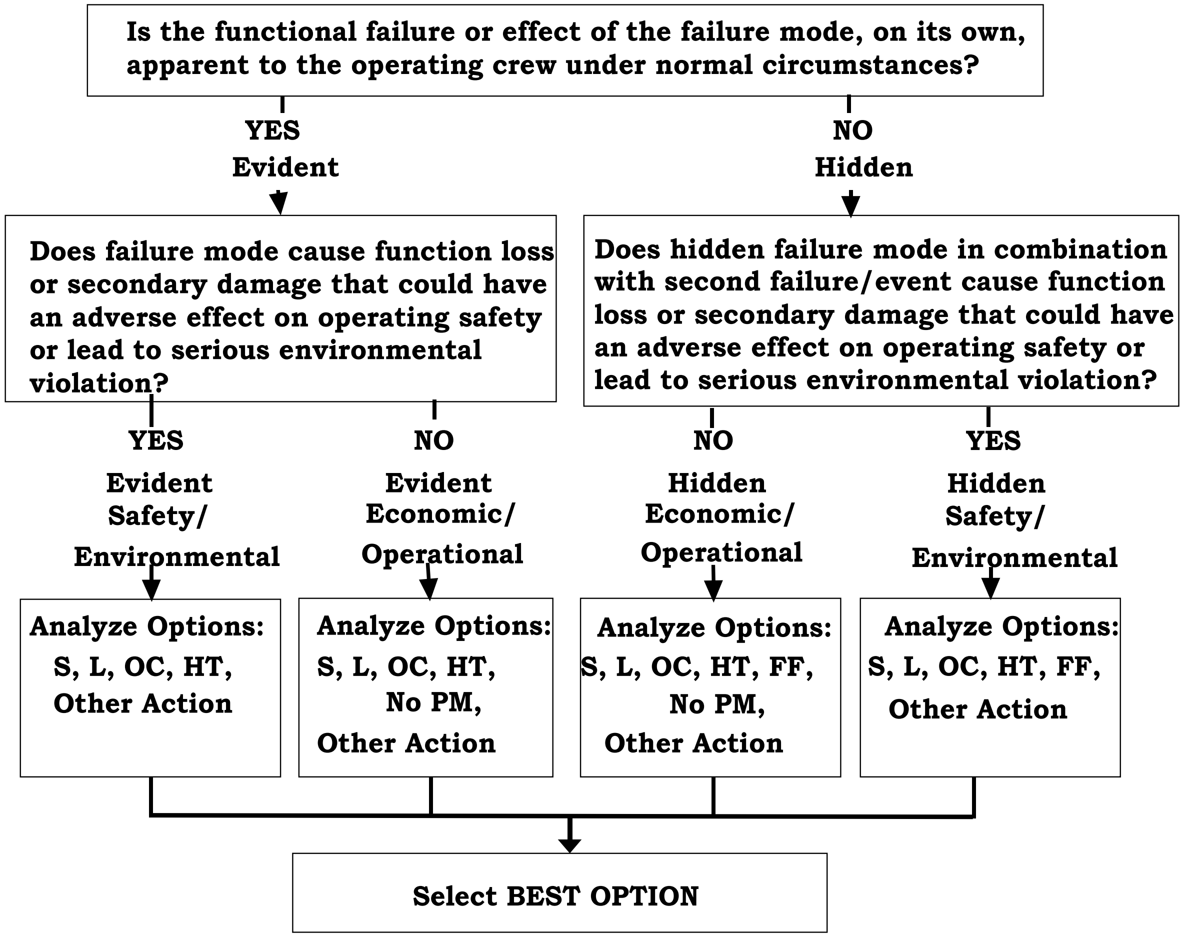


Figure 3.3 RCM Decision Logic

3.4.1 Failure Consequences

The following three questions in the RCM Decision Logic determine which branch will be used for assessing a particular failure mode to determine if a PM task is necessary or desired:

- Is the functional failure, or effect of the failure mode, on its own, evident to the operator while performing normal duties?
- Does the occurrence of the failure mode cause a function loss or secondary damage that could have an adverse effect on operating safety or lead to a serious environmental violation?
- Does the occurrence of the hidden failure mode in combination with a second failure or event cause a function loss or secondary damage that could have an adverse effect on operating safety or lead to a serious environmental violation?

Failure consequence evaluation is a two-step process. First, functional failures are separated into two categories: those that are evident to the operator/operating crew and those that are not. Second, the effects of the failure are evaluated to identify those that affect safety or environmental compliance.

For a functional failure to be classified as “evident,” it must be evident to the operating crew on its own, under normal circumstances. This means that no other failure or event needs to occur to make the functional failure evident, and no special actions or special conditions have to take place, other than those that are part of regular operations. Systems are often designed with visual or audible warning devices to make failures evident. Other failures are evident due strictly to their operational effects, for example, vibration or loss of control. Detecting the failure must not require operator actions other than those considered “normal duties” in order for the failure to be classified as evident. If the operator has to do anything not considered normal procedures to detect a failure (e.g., remove panels during equipment operation), the failure will be classified as “hidden.”

Some functions are normally dormant and only become activated upon occurrence of a "demand event". If the operational capability of these functions is not known until they are called for (i.e., there is no indication that they are in a failed state prior to the "demand event"), then failures are not apparent under normal circumstances and will also be classified as "hidden". Examples include ejection seat functions, emergency devices, and other systems with infrequent use (unless there is an effective built-in test or indication that alerts the operator to their failure prior to demand).

Once functional failures are separated into hidden and evident categories, failure modes that affect safety or environmental compliance are identified. Failures are considered to affect safety if they have an unacceptable probability to unintentionally kill or severely injure someone. In making this determination, consideration must be given to the operating crew, maintenance personnel, bystanders, and any other personnel that could be affected by the failure. Failures are considered to affect environmental compliance if they have an unacceptable probability to cause a serious violation of an environmental standard or regulation. A serious violation would be one that would do significant permanent damage to the environment, or carries penalties (such as fines or criminal prosecution) that could affect the viability of the operating organization or its people.

Evident failures that have adverse impacts on safety or environmental compliance resulting from the loss of function (including any secondary damage that was caused by the occurrence of the failure mode) require action (on-condition task, hard time task, or other action) to avoid unacceptable consequences. If more than one failure management strategy can acceptably satisfy the safety or environmental concern, further analysis is required to choose the best option by factoring economic and operational impacts.

When hidden failures are analyzed, the loss of function and any secondary damage caused by the hidden failure, in combination with a second failure or event (that makes the hidden failure evident), are considered when determining the impact of the failure. Hidden failures that have adverse impacts on safety or environmental compliance when combined with another failure/event (including any secondary damage that was caused by the occurrence of the failure mode) also require action (on condition task, hard time task, failure finding task, or other action) to avoid unacceptable consequences. Note the failure finding task option is unique to hidden failures, since the possibility exists to find and fix the hidden failures and ensure availability, when called upon, to an acceptable level of probability.

Evident and hidden failures that do not affect safety or environmental compliance will require analysis to determine the best failure management strategy by comparing costs and operational impacts of various options.

3.4.2 Decision Logic Branches

The Decision Logic consists of the four branches listed below and as illustrated in Figure 3-3:

- Evident Safety/Environmental Consequences
- Evident Economic/Operational Consequences
- Hidden Economic/Operational Consequences
- Hidden Safety/Environmental Consequences

All four branches of the Decision Logic tree may evaluate up to four types of PM tasks: Servicing tasks, Lubrication tasks, On Condition tasks, and Hard Time tasks. Two branches, the Hidden Safety/Environmental Consequences and the Hidden Economic/Operational Consequences, may also consider Failure Finding tasks. "No PM " (allowing the failure to occur), is an additional option for Economic/Operational failure modes. These failure management strategy options, along with Other Actions or combinations of options, are compared to determine the most appropriate failure management strategy.

3.5 TASK EVALUATION

Task Evaluation is the process used to determine which of several options is best suited to prevent a failure mode from occurring or, if not preventing it, to reduce the consequence of its failure to a level that is acceptable to the program. Each option has unique criteria that determine if the task is appropriate for the failure mode. During conduct of the analysis, all reasonable options should be evaluated for comparison. PM task options are presented in an order that is generally progressive in their impact to operations and economics. Some options may not be appropriate for the failure mode under evaluation, while others may be shown clearly unacceptable in cost or economic impact with only cursory review. It is not the intent of this process to generate analysis effort that is of little value. If it is apparent that a PM task option (such as an On-condition task) offers an acceptable failure management strategy and is clearly superior to other potentially acceptable options (such as a Hard Time task), the analyst should document the basis for that conclusion rather than developing extensive data to support an obvious conclusion. Regardless, the "No PM" option should be defined for comparison, even if only rough estimates of the variables are available.

3.5.1 Servicing Task

A Servicing task entails the replenishment of consumables (e.g., fuel, oil, oxygen, and nitrogen) which are depleted during normal operations.

Servicing tasks are scheduled according to need. Servicing tasks do not normally require extensive analysis to determine how often they should be performed. They are typically performed according to the manufacturer’s recommendations or operational needs considering usage, environment, and convenience. Sources of information for determining when to perform

Servicing tasks include equipment drawings, Original Equipment Manufacturer (OEM), operator/maintainer inputs and maintenance publications.

There may be occasions where servicing intervals can be determined/extended by more detailed analysis of the time to depletion. However, unless the servicing tasks entail significant maintenance resources or difficulties (such as management of hazardous material or significant disassembly), it is usually sufficient to assign the servicing task a conservative interval at a convenient point in the maintenance program to check and replenish, as necessary.

There may be circumstances where failure modes could be prevented by replacement of consumables (rather than simple replenishment), such as changing out a fluid due to deterioration. These are considered Hard Time tasks, since they entail more than replenishment and should be analyzed using the guidance of section 3.5.6.

3.5.2 Lubrication Task

A Lubrication task is the application of a lubricant to components whose design specifies lubrication for proper operation. A Lubrication task is appropriate only if the lubricant to be used is a non-permanent type and needs to be reapplied periodically.

Lubrication tasks are scheduled according to the life expectancy of the lubricant. Similar to servicing tasks, Lubrication tasks are generally inexpensive to perform and therefore, extensive analyses to determine how often they should be done are usually not warranted. Intervals are typically assigned conservatively according to the manufacturer’s recommendations, scheduled with other maintenance for convenience, or driven by other activities such as aircraft wash. Considerations such as usage or environmental exposure may affect the assigned interval for the Lubrication task. Sources of information for intervals for Lubrication tasks include equipment drawings, OEM, maintenance publications, operator/maintainer inputs and the lubricant manufacturer’s data.

There may be occasions where benefit can be gained by more thorough analysis of the deterioration of the lubricant, such as when the lubrication task takes more than nominal time, entails complications such as shutdown of continuously operating equipment or requires hazardous material under limitations on use/exposure. Methods similar to those used to determine Hard Time tasks described in section 3.5.6 would be appropriate for determining lubrication intervals based on rates of deterioration, when justified. If lubrication is applied based on the results of inspections for deteriorated conditions, the on condition methods of section 3.5.5 could be appropriately utilized.

3.5.3 Corrosion Preventive Compounds

Most corrosion preventive compounds (CPC) can normally be addressed by a Servicing or Lubrication task, dependent on the nature of the CPC (i.e., is it replenished or reapplied).

3.5.4 Servicing/Lubrication Task Cost Analysis

The cost of the Servicing/Lubrication task must be calculated in order to compare this option to other methods of dealing with the failure mode.

C_{SL} = *Cost Of One SL Task*

= (*man-hours* to perform task) x (cost per man-hour) + cost of *materials*

3.5.5 On Condition Task

An On Condition task is defined as a periodic or continuous inspection that is designed to detect a potential failure condition and allow correction prior to functional failure. A potential failure is a definable and detectable condition that indicates that a functional failure will occur. In the event that the inspection reveals a potential failure condition, some corrective action must be taken. If the potential failure condition is not present, nothing is done, and the item continues in service until the next inspection. The On Condition task includes only the inspection phase of the maintenance evolution. An On Condition task allows an item to be left in service until a potential failure is detected, thereby maximizing its useful life while minimizing repair costs and the number of spares required. Also, since an On Condition task is normally the least intrusive of the PM task options, the likelihood of inducing damage/failures is reduced. The complexity of On Condition tasks ranges from simple visual inspections to complex non-destructive inspections requiring specialized equipment including imbedded PHM systems.

3.5.5.1 On Condition Task Development

To develop an On Condition task, the following questions must be addressed:

- What is the Functional Failure? (This can normally be obtained from the FMECA data, however, additional definition or clarification related to the specific failure mode may be required during development of the On Condition task.)
- What is the Potential Failure?
- What is the Potential Failure to Functional Failure (PF) interval; is it consistent?
- Can a task interval be developed that ensures the probability of failure is at an acceptable level (considering the consequences of the failure mode)?

Figure 3-4 illustrates these questions.

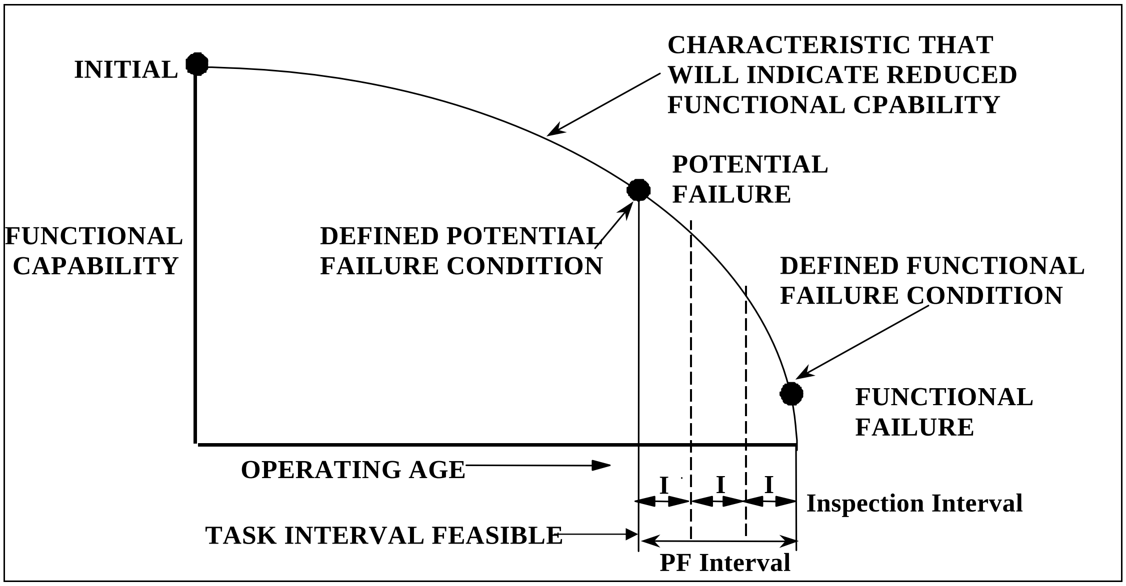


Figure 3-4 On Condition Task Considerations

3.5.5.2 Identifying the Functional Failure Condition

When a function ceases to perform its normal or characteristic action(s) within the acceptable limits specified by the user, a functional failure is said to have occurred. The problem of determining what constitutes a functional failure condition is generally less difficult than defining a potential failure condition. This is because when a function ceases to exist, something tangible and measurable is lost to the operator; whereas, with the potential failure condition, functionality has not been lost, and therefore, is more difficult to define. Functional failures are identified and documented during failure mode and effects analyses, but potential failures are not considered during these processes. However, during conduct of the RCM analysis, it may be necessary to more specifically define the functional failure condition related to a specific failure mode to aid in development of the failure management options. For example, a functional failure of primary structure may be the inability to support a specific load. The failure mode may be fatigue cracking. However, to define the PF interval, the specific crack length that is considered unacceptable to continue in operation is required to define the functional failure condition for the fatigue cracking failure mode. Once determined, it is usually helpful to add this information to the FMECA for future reference. The IRCMS software also requires this information for the On Condition task analysis.

3.5.5.3 Identifying the Potential Failure Condition

The potential failure condition is a specific and detectable level of degradation. Setting the potential failure condition as the first detectable indication of degradation will maximize the On Condition task interval. Defining the potential failure condition further down on the degradation curve, i.e., closer to the functional failure condition, may allow the item to remain in service longer, but requires on-condition inspections to be performed more frequently.

The potential failure condition that is defined must be consistent with the failure detection technique being proposed. A failure mode may exhibit several different degradation characteristics that can be used to reveal a potential failure condition. For example, several valid potential failure indicators for the failure mode “wear” could be considered. Among these include a specific amount of material lost through wear, a level of vibration induced by a worn segment of a rotating component, or the intensity of heat generated by friction associated with wear. When deciding which characteristic to use as an indicator of failure resistance, consider the length and consistency of the PF interval, the availability of measuring equipment and, ultimately, the cost effectiveness of the resulting On Condition task. It is often helpful to do a trade-off analysis to determine which approach is most effective, when multiple approaches are deemed acceptable. Various tools and the IRCMS software could be used in doing these kinds of trade-offs.

3.5.5.4 Determining the PF Interval

Various methodologies are available for determining or estimating PF intervals; these include laboratory testing, analytical methods, evaluation of in-service data, and engineering judgment based on inputs from operators and maintainer, and knowledge of the item’s design and of applications consisting of similar components. The method used to determine the PF interval depends on the nature of the failure mode.

An Age Exploration (AE) task can be used in many cases to collect the data needed to refine a PF interval when it is otherwise difficult to do so. If a reasonable and consistent PF interval cannot be determined, then some task other than an On Condition task must be considered.

The On Condition task interval is based on the PF interval. A failure mode could have a random failure mode pattern, and still have a consistent PF interval. It is not the frequency or probability distribution of the failure mode that establishes the appropriateness of an On Condition task, but rather the progression of the failure mode once it begins. It is also important to understand that individual PF intervals will likely vary to some degree from item to item within a population of like items. For example, one item might exhibit a PF interval of 700 hours, another at 920 hours, and still another at 650 hours. When the PF interval is relatively consistent across the population as in this case, it is easy to establish an interval that applies to every member of the population. However, when individual PF intervals vary widely, it becomes more difficult to establish one interval that can be effectively applied to the entire population. For failure modes that result in evident safety/environmental or hidden safety/environmental failure consequences, the shortest PF interval of the range should be selected. The resulting On Condition task interval will appear conservative; however, the short PF interval is necessary in order to ensure the protection against severe failure consequences for all individual items. If an effective lower limit for the PF interval cannot be determined, or if the interval is too short for practical application for one type of degradation indicator, a different degradation indicator may allow a longer interval if it can detect potential failure at an earlier point in the degradation cycle. If this approach fails, then another type of task should be considered.

One method of conducting On-condition inspections at very short intervals is through on-board or imbedded PHM sensors and monitoring devices. These devices are becoming more prevalent and dependable and may offer advantages in reductions in disassembly and physical inspection. Section 3.7.1 discusses use of this technology for performing On Condition inspections.

3.5.5.5 On Condition Task Interval Development

The purpose of an On Condition task is to reduce the probability of functional failure to an acceptable level by detecting potential failures before they progress to the functional failure stage. The PM task interval is determined by using some fraction of the PF interval. This fraction will depend on the consequences of failure and the effectiveness of the proposed task. This is discussed in more detail in Appendix A. This concept is represented by the formula:

$$I = PF/n$$

Where:

I = Inspection interval

PF = potential failure to functional failure interval

n = number of inspections in the PF interval

For failure modes with safety/environmental consequences, an On Condition task is acceptable if a task and interval can be identified that will reduce the probability of experiencing a functional failure to an acceptable level. For failure modes with hidden safety/environmental consequences, an On Condition task is acceptable if a task and interval can be identified that will reduce the probability of experiencing a multiple failure (or failure on demand for protective functions required upon the occurrence of a demand event) to an acceptable level. The acceptable level(s) of probability will be established by the program team and should be documented in the RCM Program plan. The acceptable level can be one acceptable level of probability for all safety/environmental consequence failure modes, or may vary by failure mode based on Severity codes, operational environments, failure effects, or other factors. It may be that the acceptable probability of failure for a failure mode is dependent on mission assignments (e.g., high-risk missions may accept higher probabilities of failure). Whatever factors and methods are used for establishing the acceptable levels, the proposed task must be expected to achieve the minimum acceptable level, regardless of cost or operational impact.

For some failure modes, the probability of failure may be extremely low for an initial operating period, such that the initial inspection can be delayed. In this case, the on-condition task interval would begin after this initial operating period, sometimes referred to as the "failure-free" period. This becomes the initial inspection interval, with recurring inspections based on the PF interval.

For failures that result in economic/operational consequences, an On Condition task is acceptable if it can be shown to be cost and operationally effective. Cost effectiveness is demonstrated if the projected life cycle costs with the On Condition task in place are less than the projected life cycle costs with No PM. Operational effectiveness is more difficult to demonstrate and may require involvement from the operational community to ensure the resultant probability of failure and any operational impacts from task accomplishment are acceptable. In some applications, operational impacts can be quantified in economic terms allowing a comparison between the On Condition task and No PM to be strictly on the basis of economic impact. If not, the task must be shown to be cost effective as compared to No PM, without imposing any unacceptable operational impacts.

Appendix A provides some proven methods for determining task intervals. Other methods not listed in Appendix A may be determined applicable. The method chosen must be logically and mathematically supportable. For example, it has been shown that "n" (the number of inspections in the PF interval) should not be less than one for the most cost effective On Condition tasks, therefore methods that result in "n" of less than one should be avoided. Selection of methods must also consider accuracy and availability of required data, and the specific failure mechanism being analyzed. Regardless, the method(s) adopted for determining task intervals should be documented in the program’s RCM plan.

3.5.5.6 On Condition Task Cost Analysis

The cost of the On Condition task must be calculated in order to compare this option to other methods of dealing with the failure mode.

C_{OC} = cost of one inspection (includes cost of material, labor, etc., for inspection, but not repair costs); or (man-hours to perform task) * (cost per man-hour) + cost of materials

3.5.6 Hard Time Task

A Hard Time task is defined as the scheduled removal of an item or a restorative action at some specified maximum age limit to prevent its functional failure. A Hard Time task may be appropriate when a failure mode does not exhibit characteristics that demonstrate a detectable reduction in failure resistance, or allow a PF interval that is long enough to permit an On Condition task. Unlike an On Condition task, which allows corrective action to be performed when a failure is impending, a Hard Time task removes or restores the item at a predetermined age regardless of whether or not failure is impending. After an item is removed by a Hard Time task, it is either reworked or discarded. If it is to be reworked, the item's acceptable level of failure resistance must be restored, and the item returned to service. If the item is discarded, it is replaced with a new item.

Although items that are to be reworked or discarded are treated differently once removed from service, the hard time limits for both are determined using the same methods. The RCM analysis typically does not make a distinction between rework tasks and discard tasks. How the item is treated after it is removed from service is determined by its design and maintenance philosophy via the maintenance planning process. However, the RCM analyst/team should ensure any proposed rework task deals with the failure mode being analyzed in an adequate manner to restore it to an acceptable level for the next operating interval. Often this means establishing a baseline condition that must be met during the rework process, or may involve replacement of component parts regardless of condition (i.e., parts subject to wear, fatigue, or age degradation). Rework processes that "inspect and repair as necessary" should be evaluated closely as they may not be consistent with the restoration of the equipment to a level of failure resistance sufficient for the next Hard Time interval. If the wear out age after rework is reduced due to the inability to restore the original resistance to failure, it may be necessary to establish different Hard Time intervals for new items as opposed to reworked items. These kinds of approaches will require special handling in the RCM analysis and associated documentation, and should be accomplished under the guidance of personnel well versed in the RCM process and philosophy.

3.5.6.1 Hard Time Task Development

To develop a Hard Time task that can prevent a failure mode from occurring, three questions must be addressed:

- What is an identifiable wear out age?
- What percentage of items survive to that wear out age?
- Can a task interval be developed that reduces the probability of failure to an acceptable level?

3.5.6.2 Wear Out

Wear out is described as an increase in the conditional probability of failure with age. Figure 3-5 shows a curve that exhibits wear out of an item. Some items show a well-defined wear out region, or wear-out age, where a significant increase in the conditional probability of failure occurs. Other items show a steadily increasing conditional probability of failure that may support a hard time limit.

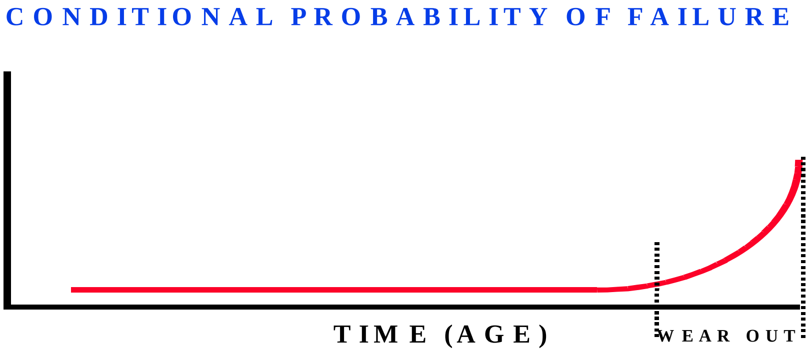


Figure 3-5 Wear Out Characteristics

3.5.6.3 Survival to Wear Out Age

Task intervals for items exhibiting wear out characteristics typically are stated in terms of Life Limits. Two terms are used to distinguish between items having age-related life limits that affect safety and those that impact economics only. The terms are Safe Life Limit and Economic Life Limit.

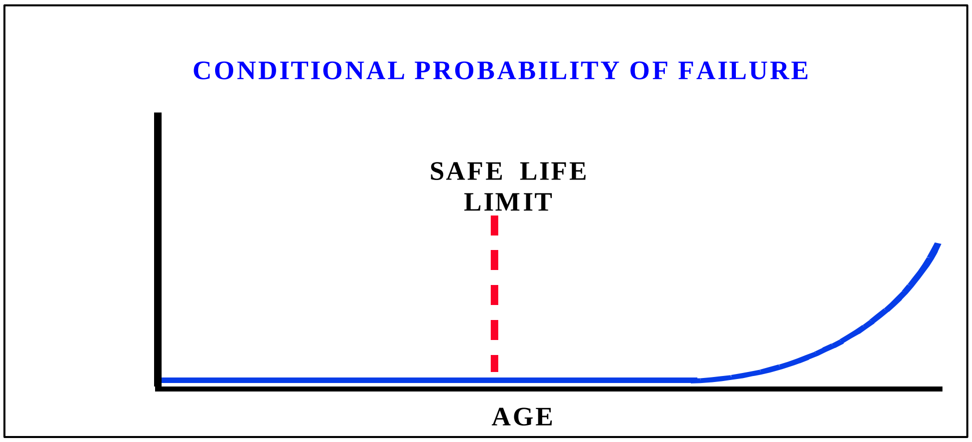


Figure 3-6 Safe Life Limit

A Safe Life Limit item must survive to an age below which no failures are expected to occur. This is illustrated by Figure 3-6. Safe Life Limits are imposed only on items whose failure modes have Safety/environmental consequences.

Economic Life Limits are used for items whose failure modes have only Economic/Operational consequences. An Economic Life Limit is warranted for an item if it is cost-effective to remove it before it fails. Unlike Safe Life Limits, which are set conservatively to avoid all failures, Economic Life Limits may be set liberally to maximize the item's useful life and, therefore, may add to the risk of an occasional failure. Figure 3-7 illustrates the characteristics attributed to Economic Life Limited items. An item with a steadily increasing conditional probability of failure may support an economic life limit, even without a well defined wear out age, if the benefits of restoration to a lower probability of failure exceed the cost.

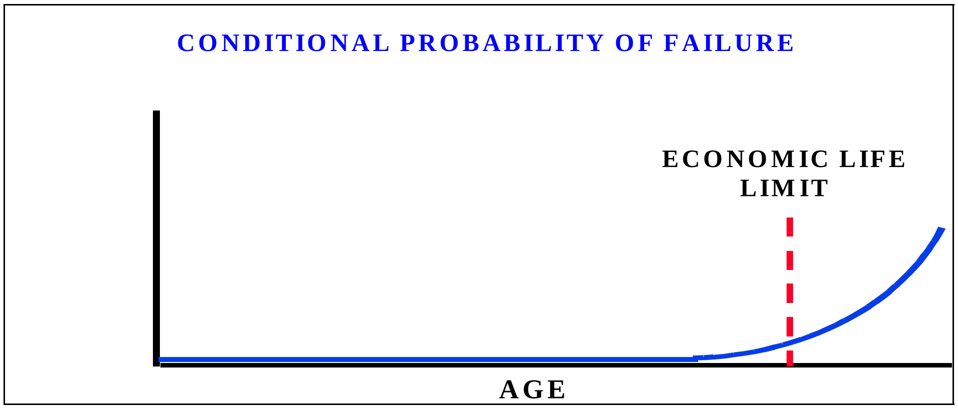


Figure 3.7 Economic Life Limit

3.5.6.4 Hard Time Task Interval Development

The task interval chosen for a Hard Time task must ensure that in-service failures are reduced to an acceptable level. Hard Time task intervals are based on wear out age or the age at which it is shown beneficial to restore or replace an item to achieve a lower probability of failure.

When safety/environmental consequences are not involved, the resulting Hard Time task must cost less over the life of the end item than allowing the item to fail in service. For a PM task to be acceptable in preventing safety/environmental consequence failure modes, the actual probability of failure with the task in place, must be less than or equal to the acceptable probability of failure. For hidden safety/environmental consequence failure modes, the actual probability of experiencing a multiple failure (or failure on demand for protective functions required upon the occurrence of some event) must be reduced to an acceptable level. See the discussion on acceptable levels of probability in Section 3.5.5.5. Actual probability of failure may be determined from a Conditional Probability of Failure Curve such as those shown in Figure 3-6 and Figure 3-7 using best available data.

Methods typically used to determine Hard Time task intervals include Weibull analysis, fatigue analysis or tests, manufacturer’s recommended service life, existing effective maintenance task, or engineering judgment based on available data, input from operators and maintainers, or similar components in similar applications. Appendix A provides some methods for determining task intervals. Hard Time task intervals for some airframe structure and structural components are identified by AIR-4.3.3 and documented in NAVAIR instructions 13120.1 and 13130.1 or Service Life Bulletins. The alteration of Hard Time task intervals for these components requires AIR-4.3.3 approval. The method(s) adopted for determining task intervals should be documented in the program’s RCM plan.

3.5.6.5 Hard Time Task Cost Analysis

The cost of the hard time task must be calculated in order to compare this option to other methods of dealing with the failure mode.

C_{HT} = *Cost Of One HT* = Cost to perform one hard time task (AVDLR or new cost)

= (*man-hours* to perform task) x (cost per man-hour) + cost of *materials*

3.5.7 Failure Finding Task

A Failure Finding task is a preventive maintenance task performed at a specified interval to determine whether a hidden failure has occurred. It is normally a scheduled inspection of a hidden function item to find a functional failure that has already occurred, but was not evident to the operating crew, such as emergency and back-up systems. When an item is subject to a functional failure that will not be evident to the operating crew, a scheduled task may be necessary to protect the availability of that function. Since failure-finding tasks are directed at functional failures, it is often possible to determine one task that can protect multiple failure modes. Failures of hidden functions that go undetected increase the exposure to a possible multiple failure or failure of protective functions when the protection is required due to the occurrence of a demand event. Therefore, Failure Finding tasks are used to reduce the probability of multiple failures (or failures on demand) to an acceptable level.

3.5.7.1 Failure Finding Task Interval Development

For a Failure Finding task to be acceptable for Hidden Safety/Environmental consequence failure modes, the probability of multiple failure (or failure on demand) with the Failure Finding task in place must be less than or equal to the acceptable probability of failure, P_{acc} established for the functional failure. See Section 3.5.5.5 for discussion on acceptable levels of probability. The probability of a multiple failure (or failure on demand), P_{mf}, is the product of the probability of failure of the hidden function and the probability of failure of the function (or the probability of the occurrence of the event) that would make the hidden failure evident. As with the previously discussed tasks, there are various methods of ensuring that the $P_{mf} \leq P_{acc}$. Appendix A provides some general methods for determining task intervals. The method(s) adopted for determining task intervals should be documented in the program's RCM plan.

3.5.7.2 Hidden Economic/Operational Failure Modes

For a Failure Finding Task to be acceptable for Hidden Economic/Operational consequence failure modes, the method used to evaluate the proposed task must show that the Failure Finding task is cost-effective. Again, the task interval can be determined in a number of ways. The method(s) adopted should be documented in the program's RCM plan.

3.5.7.3 Failure Finding Task Cost Analysis

The cost of the Failure Finding task must be calculated in order to compare this option to other methods of dealing with the failure mode.

C_{FF} = *Cost Of One Inspection* = cost to perform one Failure Finding inspection.
= (*Man-hours* to perform task) x (cost per man-hour) + cost of *materials*

3.5.8 No PM

If safety/environmental compliance is not involved, not performing PM may be the most appropriate option of dealing with the functional failure. In this case, the item is allowed to remain in operation until it fails. When safety/environmental compliance is involved, however, the functional failure must be prevented. This is accomplished by either performing a PM task, or taking some other action that is warranted.

3.5.8.1 "No PM" Cost Analysis

The cost of not doing PM must be calculated in order to compare this option to other methods of dealing with the failure mode.

C_R = *Average Repair Cost*. Includes repairing the item and any secondary damage caused by the failure. For a hidden failure, be certain to include the cost of the multiple failures. For operational consequences, if a cost of lost operations is defined, it should be included in the average repair cost. See section 3.6.1.2.

3.5.9 Other Action Warranted

If it is determined that "No PM" is unacceptable and an appropriate PM task cannot be developed that will reduce the consequences of failure to an acceptable level, then some other action must be taken. Several options, such as an item redesign (for example, improvements in reliability, introduction of PHM, or establishing redundant capability), the introduction of operational restrictions, or a change in maintenance procedures, can be applied to mitigate the problem. At times, some other action may be desirable even if a PM task is available. This course of action would be appropriate if a positive return on investment can be demonstrated in terms of, for example, increased equipment availability, reduced cost, or reduced exposure to a hazardous condition.

Finding appropriate and effective "Other Actions" is important to getting the most return from the RCM process. Finding underlying "root causes" and implementing corrective actions or improvements can lead to dramatic changes in the cost of operations, safety, and availability. Various methods have been found effective for conducting root cause analysis to determine appropriate "Other Actions". Involving the maintenance/support, operational, and design communities in the development and evaluation of alternatives is critical to finding underlying drivers to failure modes, frequencies, and effects/consequences and developing appropriate actions. One fairly simple method employed as part of the Lean process improvement techniques is the "5 Whys". This entails identifying a problem and asking "Why?" five times to uncover root causes that may be easier to correct or may need to be addressed before desired improvements can be effectively implemented. The number "5" is not critical but just illustrates the need to get below the initial obvious issues to more systematic causes. In the RCM context, this may entail identifying a failure mode, effect/consequence or frequency, and asking why it occurs, then for each answer further querying the cause of each answer. A simple example is provided as follows:

> Why are bearings wearing? Answer: Because they are overheating.
>
> Why? Answer: Because they are getting inadequate lubrication.
>
> Why? Answer: Because the lubrication system has inadequate flow.
>
> Why? Answer: Because its components are often improperly installed/adjusted.
>
> Why? Answer: Because the mechanics have inadequate training and maintenance manuals.

This example illustrates how what may have been perceived as a design problem with the bearing or lubrication system is actually more effectively addressed by improving the training and maintenance documentation available to the mechanics.

3.5.9.1 "Other Action Warranted" Cost Analysis

The cost of doing some other action must be calculated in order to compare this option to other methods of dealing with the failure mode.

C_{OA} = Development and implementation cost of the "Other Action"

3.5.10 Age Exploration (AE)

Age Exploration is used to collect specific data from actual operational or testing environments to optimize or validate RCM analysis decisions and resulting recommendations. This may include a PM task whose processes, procedures and intervals were developed based on assumptions or conservative estimates, Other Actions taken or recommended based on limited data, or No PM. Specific applications and implementation of Age Exploration are discussed in Sections 3.5.5.4, 3.7.1, 4.4, 5.2.6, and 5.3.

AE tasks can range from collecting specific in-service failure data to testing components under laboratory conditions. The RCM analysis process may be used to help assess the potential cost effectiveness and prioritization of AE tasks. A program's RCM Plan should provide detailed information on how to develop and implement AE tasks.

In acquisition or newer programs where PM is relatively immature, AE is essential and can ensure coverage of safety related failure modes through controlled laboratory testing or analysis. It can also be applied in well established programs to monitor failure modes where current RCM analysis cannot accurately predict reasonable protection due to lack of suitable information or data.

When data and information collected through AE are applied to the RCM analysis it results in either a new scheduled maintenance task, no PM or Other Action. Note that both progression and inactivity of characteristics or effects demonstrated in AE information or data should be considered in subsequent RCM analysis. Specific applications and implementation of Age Exploration are discussed in Sections 3.5.5.4, 3.7.1, 4.4, 5.2.6, and 5.3.

3.5.10.1 – Age Exploration Plan (AEP)

Developing an AE task involves many facets, each of which is required to collect the data that allows analysts to make informed RCM decisions. AE task development includes, amongst other things:

- Designing the task to include task description, initial inspection interval, task interval, task duration, and sample quantity
- Determining the level of maintenance and skills required to collect the data
- Performing a cost-benefit analysis to determine if the proposed AE task will be a worthwhile effort. This is a secondary task for safety related failure modes where a conservative default approach should be used, and revisited.
- Obtaining permission to implement the task at specific organizational activities
- Establishing lines of communication between the analyst and the data collector

In consideration of the above, an Age Exploration Plan (AEP) will help in defining an appropriate and effective scheduled preventive maintenance AE task. An AEP should consist of three basic components:

1) A “purpose” statement explaining why AE is necessary.
2) A “plan” statement that details what information will be collected, how it will be collected, when it is collected and by whom. It should detail what skills and support will be required to complete the AE task, and estimate date when the AE task will be completed or need reviewing/updating.
3) An “impacts” statement that explains any burdens and negative effects that may result by implementing AE for the specified case. Every effort to minimize impact or burden to the fleet must be made.

AE tasks should be made part of the overall maintenance program and can be included in Maintenance Requirements Cards (MRC) or Specifications, or can be issued as Age Exploration Bulletins. These tasks should be clearly identified as to their purpose such that the maintenance personnel are aware of the information requirements and ultimate use. In many cases, whether integrated in the maintenance documentation or separately handled, an AE task is most effectively accomplished in concert with regular maintenance if it can be done without adding an undue burden and disruption to the work being performed. Proper planning of AE tasks will also reduce the impact on downtime.

There will be times when AE tasks and regular maintenance tasks cannot be performed concurrently. When this happens, equipment downtime will be extended by necessity. It is important, therefore, that AE tasks, particularly those that cannot be done concurrently with regular maintenance tasks, be designed as efficiently as possible.

Another area of concern is the demand placed on maintenance resources by the addition of an AE task. Expenditure of resources must be balanced against the potential benefits of the AE task. An AE task should make use of existing support facilities, manpower and skills whenever possible. AE tasks should be designed to eliminate the need for peculiar support equipment and specialized technical training, if possible.

3.5.10.2 AE Tasks for Failure Modes with Safety/Environmental Consequences

AE tasks that are designed to collect functional failure data for failure modes with safety/environmental consequences must be done in such a way to ensure safety/environmental compliance is not compromised. When the data required by an AE task calls for the item under investigation be operated to a functional failure condition that presents a hazard to the operating crew, it is best conducted in a laboratory environment. These tasks, devised as engineering test-to-failure processes, are often accomplished for determining safe life limits on items where Hard Time tasks are being considered, but may also be used to determine PF intervals.

Safe life limits may be determined based on statistical analyses, often testing a sample of items to failure. Safe life limits are then established based on some factor below the mean age at which the sampled items failed to ensure the risk of in-service failure is reduced to an acceptable level. To achieve a safe life, the limit should be set at an age prior to any failures occurring.

AE tasks can be used to collect data on the reduction of failure resistance or degradation of items that have safety/environmental consequences, while the item is in operational use, provided that potential failure and functional failure limits have been set. Data may be collected up to the point at which a defined symptom is identified or the item must be removed. For example, an AE task may be used in the operational environment to determine the crack propagation rate for a damage tolerant structure if care is taken to ensure that the item being studied never reaches the functional failure condition. An AE task should never be used in the operational environment to validate the point of functional failure when the failure mode has safety/environmental consequences. AE task data that indicates no failures have occurred up to the time that an item is scheduled for removal is not justification for increasing the removal interval. If the item's Hard Time removal age is extended based on such evidence, the net effect is a reduction in the safety factor upon which the Hard Time removal was originally established. AE tasks that are accomplished in an operational environment must be implemented with conservative AE inspection intervals to reduce the risks of failure to an acceptable level.

3.5.10.3 AE Tasks for Failure Modes with Economic/Operational Consequences

AE tasks that are designed to collect data on items whose loss may have a significant impact on the intended mission or economics are treated differently from those that affect safety/environmental compliance. AE tasks for such items generally can be performed while the equipment is fielded or by routine monitoring of maintenance information systems; thus, controlled laboratory tasks or other off-equipment tasks are not usually required. This type of task may be conducted over a finite period to determine the effectiveness of a Hard Time task by using analytical techniques such as actuarial analyses or allowing the items sampled to fail while in service. It also may be used to evaluate the physical characteristics of equipment, such as observable failure indications, in order to assess the technical feasibility of a PM task or to determine the true consequences of a functional failure to the equipment.

3.5.10.4 AE Sample Quantity

The sample quantity is the number of items that will be inspected or tested by the AE task. Sample quantities are calculated to lessen the impact on maintenance and cost of the AE task. The sample quantity should be determined by statistical methods to ensure that the data collected is adequate to accurately represent the entire population. Conversely, the sample should be as small as possible to reduce cost and operational impact while maintaining the desired confidence level. Sample quantities are normally determined through statistical analysis techniques such as Hypergeometric, Weibull, or Poisson.

3.5.10.5 AE Task Selection

The overall safety, environmental, operational, and economic benefits of an AE task should be determined and documented within the analysis as justification for performing the task.

3.6 RCM TASK SELECTION

The task evaluation process can result in three scenarios which serve as options by which a failure effect is mitigated:

∗ Perform PM (one or more of the various types of tasks. See section 3.7.2 for discussion on combinations of tasks.)

∗ Allow the failure mode to occur, then take corrective action ("No PM" option)

∗ Take some other action, such as redesigning the item or modifying an operational or maintenance procedure

The “best” strategy for dealing with the failure mode is determined by comparing each of the available options. If an option is not immediately available (such as redesign, implementation of new technology, etc.), the analysis should evaluate currently available options for implementation and then compare the chosen option against the potential for further improvement. If the action that is not immediately available is identified as preferred to the options currently available, it should be identified as the desirable option and pursued for later implementation while executing the best immediately available option until then.

3.6.1 Basis for Decisions

Remember that at this point in the analysis each option has already been evaluated for the ability to reduce the consequences of failure to an acceptable level. Acceptable options have been identified and quantified. A failure management strategy based on any of the acceptable options will meet the program’s requirements. The best strategy will be determined by the comparing the cost and operational consequences of each acceptable option.

3.6.1.1 Cost

There are several ways to compare the cost of each option. The costs of options are typically compared by normalizing them to a common unit such as cost per unit operating hour, cost per flight hour, or cost per cycle. Costs can then be compared directly with one another to assist in making a final decision. Table 3-1 provides methods that can be used in such a manner. These methods are similar to those in the IRCMS software. However, due to the various versions of IRCMS in use and development time in updating IRCMS to incorporate improvements in these methods, the analyst should check the IRCMS version used. Some versions may have slightly different cost equations than those listed here. IRCMS incorporates the ability to insert costs in replacement of its calculated values. A program may decide to use their own set of equations or methods for comparing options, including adopting any differences between the equations below and those in the IRCMS version used. If this is the case, document the method to be used in the RCM Program Plan and in the IRCMS database. Regardless of the method chosen, ensure that the applicability and sensitivity of the method are considered.

3.6.1.2 Operational Consequences

At times, the least expensive option will not be the best solution when the operational consequences are taken into consideration. A slightly less expensive option (in terms of direct costs) may have a bigger impact to operations, such as requiring more downtime, and, therefore, may not be as desirable. If the operational impact is considered more important than the additional cost, the more expensive task should be chosen. The program must establish the methodology to be used to balance cost and operational impact. Discussion and review with maintenance and operations personnel is particularly important in evaluating operational impacts and balancing these impacts with direct costs.

The operational impact can sometimes be expressed in terms of added cost, and included in determining the “cost” of the option. At times, this is not feasible, and an operational consequence must be considered separately from cost, often in a more subjective manner. The program’s RCM plan should include additional guidance to assist in making these decisions. A part of these subjective considerations may by the level of intrusion required by the various task options. Tasks that require significant disassembly will generally have a larger cost to perform and operational impact due to the elapsed maintenance time required to perform the task. However, another consideration would be the possibility of inducing failures when performing the task. Although the potential for inducing failures is often not readily quantifiable, tasks which require greater intrusive action should be carefully considered before selection over similarly effective tasks that can be accomplished without disturbing the system.

Option	Cost Per Unit Operating Time Equations
Service and Lubrication	$\mathbf{SL_{OP} = C_{SL} / I_{SL}}$ Where: SL_{OP} = Service/lubrication task cost per operating time C_{SL} = *Cost Of One SL Task* I_{SL} = *Task Interval*
On Condition	$\mathbf{OC_{OP} = ((C_{OC} / I_{OC}) *(L - (I_I - I_{OC})) / L) + C_R / MTBF}$ Where: OC_{OP} = On-condition task cost per operating time C_{OC} = *Cost Of One Inspection* (Includes cost of material, labor, etc., for inspection but not repair costs) L = *Item Design Life* I_I = *Initial Inspection Interval* = Interval of time until the first inspection I_{OC} = *Task Interval* C_R = *Average Repair Cost*. Average cost of repairing all failures (both potential and functional failures) assuming the inspection is in place. Ensure secondary damage is included, as applicable, and, for hidden functions, include the cost of multiple failures in the functional failure portion of the cost. If operational impact has been converted to "cost", ensure it is included. NOTE: A large majority of the repair actions should be the repair of potential failures if the inspection and interval are appropriately selected. However, there may be significant costs associated with the remaining functional failures such that they should be considered in the cost evaluation. MTBF = *Mean time between failures (both potential and functional with task in place)*

Table 3-1A Cost Equations

Hard Time	**$HT_{OP} = [C_{HT} (S) + C_R (1-S)] / [(S) I_{HT} + (1-S) K I_{HT}]$** Where: HT_{OP} = Hard time task cost per operating time C_{HT} = *Cost Of One HT* = Cost to perform one hard time task S = *Percent Survive* = Percentage of items that survive to the hard time limit I_{HT} = *Task Interval* K = *Premature Failure Factor* = Average age of premature failures as a percentage of $I_{HT.}$ (*Note*: K I_{HT} is used to estimate MTTF of premature failures.) C_R = *Average Repair Cost.* Average cost of repair if HT task is not done and unit fails. Ensure secondary damage is included, and for hidden functions, include the cost of multiple failures. If operational impact has been converted to "cost", ensure it is included.
Failure Finding	**$FF_{OP} = C_{FF} / I_{FF} + C_R / MTBF$** Where: FF_{OP} = Failure Finding task cost per operating time C_{FF} = *Cost Of One Inspection* = Cost to perform one Failure Finding inspection I_{FF} = *Task Interval* C_R = *Average Repair Cost.* Average cost of repairing the functional failures considering those found by the inspection and those that become evident by multiple failures not prevented. Include operational impact if it has been converted to "cost". MTBF = *Mean time between failures (with task in place)*
No PM	**$NO_{OP} = C_R / MTBF$** Where: NO_{OP} = “No PM” cost per operating time C_R = *Average Repair Cost* Average cost to repair the functional failure and secondary damage. For hidden functions, include the cost of multiple failures. Include operational impact if it has been converted to "cost". MTBF = *Mean time between failures (with no task in place)*
Other Action	**$OA_{OP} = C_{OA} / L_R$** Where: OA_{OP} = “Other action” cost per operating time C_{OA} = *Cost of Other Action.* Total cost to develop and implement “Other Action” L_R = *Remaining life of system*

Table 3-1B Cost Equations (continued)

3.6.1.3 Cost Equation Limitations

The cost equations in Tables 3-1A and 3.1B and those used in IRCMS are only approximations of actual cost and are based on assumptions that may limit their applicability in specific situations. Careful evaluation of these limitations should be accomplished to ensure applicability of these methods. If other methods are used, ensure the results are documented in the analysis (for IRCMS users, the cost analysis may be overwritten and the memo function may be used).

One of the issues to consider in the use of these equations is the issue of MTBF. The MTBF documented in the FMECA should be determined for a failure mode assuming no PM task is in place and used to establish the cost of the No PM option. The On Condition and Failure Finding cost equations in some versions of IRCMS use the same MTBF to approximate the mean time between corrective actions (MTBCA) with the corresponding task in place, as identified in above equations. Note, for On Condition tasks, the majority of these corrective actions should be addressing potential failures, and for Failure Finding the majority should be correcting hidden failures prior to a multiple failure or demand event. Therefore, using a single MTBF, such as that provided by the FMECA, will introduce some degree of error. In these versions of IRCMS it may be desirable to override the IRCMS result with “off-line” calculations. Version 6.3 and subsequent will allow direct entry of MTBCA related to the task being evaluated, however, if only the MTBF (no task in place) is available, it should be adjusted based on the following considerations to estimate MTBCA:

- MTBCA for an item with an On Condition task in place will usually be lower than the MTBF of the same item without a PM task. If the PF interval is relatively short when compared to MTBF, the MTBF and MTBCA should be similar. Otherwise, using the Unmitigated MTBF (i.e. with no task in place) as MTBCA may cause the cost equation to significantly underestimate the cost of the failure portion of the cost equation. In these cases, MTBCA should be derived or estimated and used in the cost equation. Factors affecting the MTBCA are the detection probability of the inspection task, the frequency of potential failure on-set, the proposed inspection frequency as compared to the PF interval, and the consistency of the PF interval. If no other information is available, a reasonable approximation of MTBCA may be as follows (assumes potential failures are found at the mid-point of the PF interval, on average):

$$MTBCA = MTBF-(PF/2)$$

NOTE:

> If it is determined that the MTBF listed in the FMECA was not adjusted to account for an existing On-condition task (i.e., it is really MTBCA), the above equation may be used to estimate the No PM MTBF and update the FMECA as follows: MTBF = MTBCA + (PF/2)

- MTBCA for an item with a Failure Finding task in place will usually be higher than the MTBF of the same item without a PM task unless the MTBF is calculated recognizing that the failure is only made evident by a multiple failure or demand event. If the failure finding interval is relatively short when compared to MTBF, the MTBF and MTBCA should be similar. If the failure finding interval is a significant percentage of MTBF thereby increasing the period the function may remain in a failed state prior to detection, using MTBF as MTBCA will cause this cost equation to over estimate the actual cost of the failure. If this over-estimation is not acceptable, the MTBCA should be calculated from field data, or estimated. Factors affecting MTBCA for failure finding will be the detection probability of the proposed task, the ratio between failure on-set and the inspection frequency, and the consistency of the failure frequency. If no other information is available, a reasonable approximation of MTBCA for failure finding task may be (assumes inspections are evenly distributed around the onset of failure, with a high probability of detection):

$$MTBCA = MTBF + (I_{FF}/2)$$

If MTBF (for the hidden failure with no PM) considered failures only when becoming exposed by the multiple failure or demand event, then MTBCA will be shorter than MTBF with the same factors at play, recognizing that MTBF was based on the failures being in a failed state for some time prior to recognition and correction. In these cases, a conservative MTBCA should be established, and an Age Exploration task considered, establishing a better estimate of the actual frequency of corrective actions.

- For the "No PM" cost for hidden function items, the MTBF should be the occurrence rate of the functional failure that only becomes evident with a multiple failure or demand event. Therefore the FMECA must be checked to determine the assumptions made in determination of the MTBF entered, and adjusted if needed. If MTBF reflected actual on-set of the individual failure mode, vice the functional failures considering the multiple failure or demand event, this data will be helpful in determining MTBCA as described above and should be retained in the IRMCS memo field.

Another issue with the cost equation is the determination of average repair costs (C_R). Recognize that to determine average repair costs, you must factor the frequency of various levels of repair, along with any economic impact from lost operations (if appropriate). For example, if a potential failure costs $1000 to correct on average (considering labor, material, and lost operations) and functional failure costs $100,000 to correct (considering labor, material, and lost operations due to the failure and any secondary damage), you must also factor in the frequency of each. If 95 percent of the corrective actions are potential failures and 5 percent are functional failures in a given timeframe, the average repair cost would be ($1000 x .95) + ($100,000 x .05) or \$5950. The C_R descriptions in the above equations list the factors to be considered for each task type in determining average repair cost.

3.7 SPECIAL CONSIDERATIONS

3.7.1 Prognostics and Health Management (PHM) Systems

Several protective and diagnostic/prognostic devices and systems (termed “PHM systems” throughout this section) are available for integration into an item’s design. Basing performance of maintenance tasks on PHM systems is sometimes referred to as Condition-Based Maintenance (CBM). These systems are often capable of performing PM tasks that traditionally have been done in a physical sense by maintenance personnel. An understanding of the functions and capabilities of PHM systems is necessary to ensure that traditional PM tasks are not developed that replicates their functions. PHM systems, themselves, must be analyzed to reveal failure modes that will possibly require PM tasks. As PHM systems become more prevalent, their value in terms of reducing the time, resources, and costs of performing conventional PM tasks, must be considered. Installing PHM systems to replace conventional PM tasks should be done only after clear benefits in safety, environmental compliance, operations, or cost can be shown. This is true regardless of whether the devices are being applied to new acquisition designs or to in-service equipment. Finally, but no less important, consider the cost of implementing and maintaining the additional PHM system or device. Therefore, PHM or CBM programs must be based on a well-developed RCM analysis.

State of the art PHM systems are capable of detecting potential failure conditions down to the component or sub-element level. They are also able to monitor the progression of chosen failure mode indicators, e.g., heat, vibration, etc., to predict when functional failures will occur. Through automated monitoring, a “prognosis” of the “health” of the component can be made. Item degradation is monitored automatically as it progresses to a defined potential failure condition, at which time some maintenance action is warranted. PHM systems may essentially perform “automatic” on-condition inspections at predefined intervals, which often are extremely short or nearly continuous. They use on-board sensors, algorithms, and diagnostic indicators (or indices) that are sensitive and accurate enough to detect or predict the potential failure condition. The effectiveness of these systems depends, to a large degree, on having a reliable database consisting of similar types of “faults,” which can be used to establish failure progression rates and proper thresholds for setting appropriate alarms or actions.

When developing a FMECA, any PHM system that is used to monitor some aspect of the item undergoing analysis must be considered. This will help ensure that compensating provisions, failure detection methods, and failure effects are properly stated. PHM systems may have failure detection methods or compensating provisions that are different for potential failures than for functional failures; therefore, care must be taken to identify the level of failure being monitored or protected.

In deciding what functions are significant, remember that a PHM system may essentially be performing an automated PM task. When this is the case, ensure that the function protected by the automated inspection or monitoring system is considered for inclusion in the analysis.

When identifying failure consequences, take care that PHM systems (which provide failure detection, indication or prognosis of another system or item) are properly analyzed. Failure of the PHM system, itself, may not be obvious and, therefore, be “hidden.” In essence, a hidden function may be eliminated from one system and added to another system by incorporating a PHM system.

When evaluating servicing and lubrication tasks, keep in mind that some items may have PHM systems, which are designed to automatically provide indications that the monitored consumables need to be replenished. Servicing and lubrication tasks do not require or depend on scheduled events when these systems are installed. PHM technology may also be used to identify the need for lubrication based on sensed or derived information such as vibration, heat generation, speed of actuation, etc. Additionally, newer PHM technology may be used to predict deterioration of corrosion protective and preventive material using corrosion sensors. The functions of these sensors must be included in the RCM analysis with consideration given to what the consequences will be if the sensors fail.

When evaluating on-condition tasks, consider PHM technology and systems that introduce the potential for automated on-condition inspections through on- and off-board devices. An RCM analysis should be performed to determine where and how this technology might be applied to new acquisitions. The analysis can be used to some extent to calculate sensing sensitivities and frequencies, to set potential failure condition values. The functions of PHM systems, themselves, must be considered in the analysis to ensure that the high levels of reliability required to ensure their effectiveness are maintained. Consider also, the need to monitor or validate the effectiveness of these systems during RCM sustainment and Age Exploration task evaluations. This can be done by periodically validating that the assumptions and capabilities of the PHM systems to predict failures are consistent with actual equipment conditions.

PHM systems with on-board sensors are often designed to detect potential failure conditions by performing automated On-Condition inspections. These types of PHM systems could be used under circumstances that preclude the use of conventional On Condition tasks; for example, when PF intervals are too short. The “inspection interval” for the PHM system is the rate at which equipment condition is sensed. The sensing rate can be so fast that it is, for all practical purposes, nearly continuous. For this reason, some PHM systems can instantaneously initiate preventive or protective actions automatically. For example, if a potential failure condition is detected by a PHM system while the equipment is in operation, it may be set to automatically switch to a backup system, thus allowing the operation to continue without interruption. The degraded system can then be replaced after the mission is finished.

PHM systems may be used to automatically track the age or usage of components to promote cost-effective management of Hard Time tasks. In this context, however, they are not sensing degradation, but merely usage. PHM technology can reduce costs by automatically tracking age and triggering replacement or restorative actions. PHM systems can be used to reduce or eliminate the dependence on manual tracking systems or tracking parameters that not are easily tracked, such as actual power-on time. Note that, in this context, the Hard Time task interval still needs to be determined via RCM analysis.

In evaluating Failure-Finding tasks during an RCM analysis, PHM technology may be considered as an alternative to physical inspections where it can be shown effective in reducing costs or offering benefits with regard to safety, environmental compliance, or operations. PHM technology in this context is not sensing degradation, but actual functional failure of the monitored system. When PHM systems are incorporated into the equipment design, they must be included in the FMECA so that their failure modes can be considered for RCM analysis.

Failure modes that are protected by PHM systems are prime candidates for being monitored during the RCM sustainment phase or validated by Age Exploration tasks. There may be a need to validate the assumptions or algorithms used initially to predict equipment condition by comparing them to the actual in-service condition. The methods chosen to conduct validation requirements should be based on factors that include the degree of confidence in the sensing or predictive technology and the consequences that will result if a PHM system fails. Periodic sampling, fleet leader sampling, and trend analyses often can be used effectively to gather this data during the RCM sustainment phase.

3.7.2 Combination of Tasks

Sometimes no single task can be found that adequately reduces the probability of failure to an acceptable level. In these cases, it is sometimes possible to combine tasks (usually of differing types) to achieve the desired level of reliability. When considering combinations of tasks, the effectiveness and costs of the tasks must be carefully considered. When considering a combination of tasks as an option, ensure when comparing costs that failures and repairs are adjusted to account for both tasks. For example, if on condition and hard time tasks are combined, the frequency of failures/repairs may be less due to removing items at a specified age (and not subjecting them to failure). Also, the cost of the premature failures for the hard time task should be less due to finding them at a potential failure stage vice at functional failure.

3.7.3 Zonal Inspections and Walk-around Checks

In contrast to RCM justified PM tasks, zonal inspections and walk-around checks do not fall within the realm of RCM task definition, as they are not normally targeting specific failure modes, but are used to ensure integrity (e.g., proper installation), discover unanticipated or accidental damage, or verify readiness for operations.

In general, walk-around checks and integrity validations are good maintenance practices when implemented on the basis of opportunity requiring minimal additional resources, but care must be taken to ensure they supplement the maintenance program rather than define it. Similarly, Age Exploration inspections are useful when new equipment is introduced and there is little operational data available to accurately define the type and frequency of failures that may occur. However, as operational data is accumulated, defects detected during these examinations should be evaluated to determine if specifically directed maintenance is necessary and reliance on default inspections should be reduced accordingly.

In reality, no matter how thorough the RCM analysis, unanticipated failures and unforeseen exceptions to failure behavior occur. It is important to evaluate the impact of these events and incorporate appropriate failure management strategies rather than rely on cursory inspections such as walk-around and zonal inspections.

3.7.4 Event-Driven Tasks

Another category of maintenance tasks is event-driven tasks, often referred to as "conditional maintenance" requirements. These tasks are the result of exposing equipment to unanticipated loads or extreme usage that may cause the normal failure mechanism to be accelerated to such a degree that it cannot be confidently assumed that RCM derived maintenance requirements are still satisfactory to achieve adequate failure management. Examples, of these types of inspections are tests and checks performed after exposure to extreme conditions such as hard landings, extreme temperatures, potential overloads, excessive vibration, buffeted flight, harsh operations or environment (e.g., overspeeds, abnormally high utilization, long at sea conditions, corrosive material exposure), and unusual weather conditions (e.g., hail, high winds). Sometimes these event driven failure modes can be defined uniquely and intervals determined based on repeated exposures, but often these kinds of tasks or checks are most appropriately handled as Other Actions (and included in IRCMS as such).

3.7.5 RCM Approvals and Assessments

The RCM Implementation Manager shall establish a method of review and approval that ensures the RCM methodology is properly and effectively applied, and to maintain an audit trail of RCM recommendations and implemented actions. The RCM approval process shall also ensure resultant failure management policies are consistent with failure modes and associated information. The RCM approval process should be described in the RCM Program Plan.

Examples of areas to highlight during RCM review/approvals include:

- Ensure consistency between described failure effects and RCM failure consequence categorization
- Ensure proper application of RCM task selection criteria.
- Ensure On-Condition tasks are only applied to failure modes that degrade in a way that a potential failure is clearly identifiable (and distinct from functional failure) and has sufficient progression until functional failure for a stable PF interval. Ensure compatibility between the PF and inspection intervals to achieve the desired probability of failure or cost effectiveness. Ensure inspection technique is consistent with potential failure mode identified. Ensure compatibility between maintenance manuals and RCM assumptions (for potential failure conditions and repair actions taken).
- Ensure Hard Time tasks are only applied where wear out exists and benefits are clearly shown.
- Ensure Failure Finding tasks are only applied to Hidden Function failure modes, and provide clear benefit over other options.
- Ensure accuracy and consistency in data used for analysis decisions such as cost data, maintenance/reliability data, and criticality determinations.

In addition to the RCM review/approval process, periodic assessments of RCM programs may be conducted by the associated Program Manager's team, or by the NAVAIR RCM Steering Committee. Areas that may be included in an assessment include:

- Review of the latest approved RCM Plan. Areas of interest include:

    Is staffing in place to support the Plan?

    Is adequate funding allocated to perform the plan?

    Are basic program parameters, including ground rules and assumptions adequate?

- Are the RCM analyses conducted in accordance with the plan? Are techniques defendable, applicable and are results documented such that decisions are supported and well understood? (The assessment should include review of a sample of analyses of systems that cover the various types of systems analyzed (i.e., structural, mechanical, electrical/electronic, propulsion, etc.) and a variety of senior analysts to ensure correct and consistent approaches are applied.)
- Is adequate engineering and logistics support available? Are individuals trained/certified to an appropriate level?
- Does the maintenance program as documented in MRCs and specifications reflect the RCM results?
- Are methods to update maintenance requirements based on feedback from in-service activities (i.e, age exploration, continuous monitoring, etc.)?
- Is there an approach for identifying and prioritizing RCM shortfalls of the maintenance program identified, and are they being addressed to achieve full RCM support for all preventive maintenance requirements in accordance with the approved RCM plan?

SECTION IV

IMPLEMENTATION OF RCM ANALYSIS RESULTS

4.1 INTRODUCTION

Implementation of an RCM program encompasses much more than just performing analyses. After the RCM task evaluation and selection processes have been accomplished, the resulting outputs must be implemented before the program can receive any benefit from them. The actions required of the outputs from the RCM process will be evident in several forms, including developing PM tasks, redesigning hardware, and modifying operating and maintenance processes and procedures. This section addresses the issues required to implement the results of an RCM analysis. Figure 4-1 illustrates where "implementation" is situated in the overall RCM program.

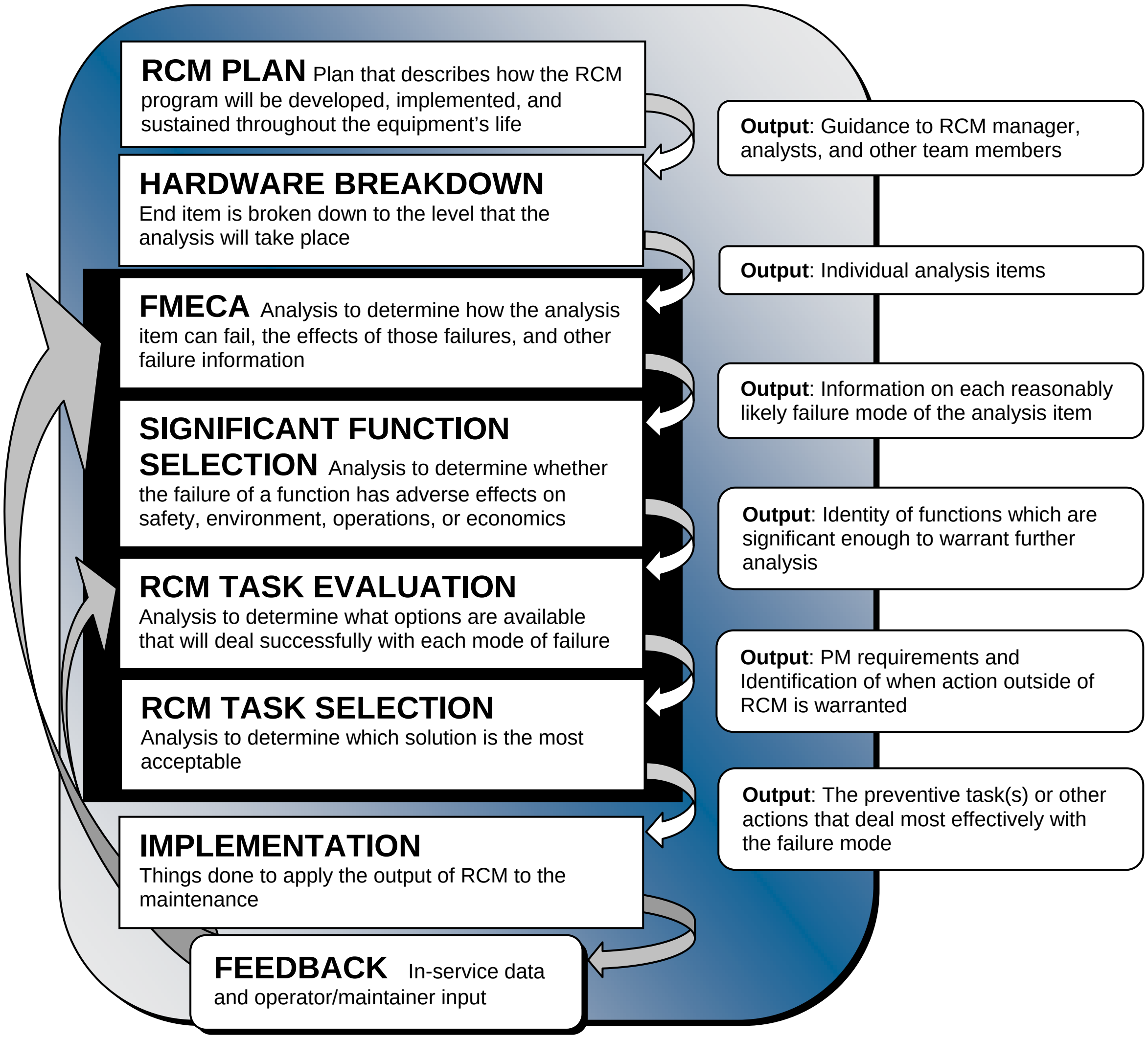


Figure 4-1 RCM Process Steps

4.2 PACKAGING PM TASKS

Once all items within the scope of a project have been analyzed, it is necessary to package the tasks into discreet work packages and intervals. The packaging process is the mechanism by which task frequencies and maintenance levels are adjusted. A PM program that is packaged properly is more cost effective than one that is not.

Prior to any packaging effort, the tasks that were produced from the RCM analyses should be reviewed to verify that they are assigned using the proper metrics. For example, the frequency for inspecting brake lining for wear should be based on a function of use, e.g., brake application, not calendar time.

4.2.1 Initial Packaging Strategy

4.2.1.1 Step 1 - Lay Out Tasks by Interval and Preliminary Maintenance Level

Once it has been verified that all maintenance requirements have been analyzed according to the proper metric, it is prudent to structure them along a timeline. It is best to include tasks at all maintenance levels on the same timeline initially since, in effect, it will illustrate where repackaging with another maintenance level is desirable.

In building a timeline, it may be necessary to convert the metrics of some tasks in order to organize them effectively. Alternatively, it may be necessary to create multiple timelines with different metrics. Extreme care should be taken when converting a task from one metric to another since the conversion is usually an approximation. If a safety/environmental related task is converted to another metric, the conversion must be based on the worst-case scenario. For example, assume that the result of an RCM analysis indicates that it is necessary to inspect the bushings in a rudder attachment fitting for wear every 500 flight hours. If the average aircraft usage were 50 hours per month, simple arithmetic would suggest that inspecting for wear every 10 months is acceptable. However, consider the two distributions of aircraft flight hours illustrated in Figure 4-2 and Figure 4-3.

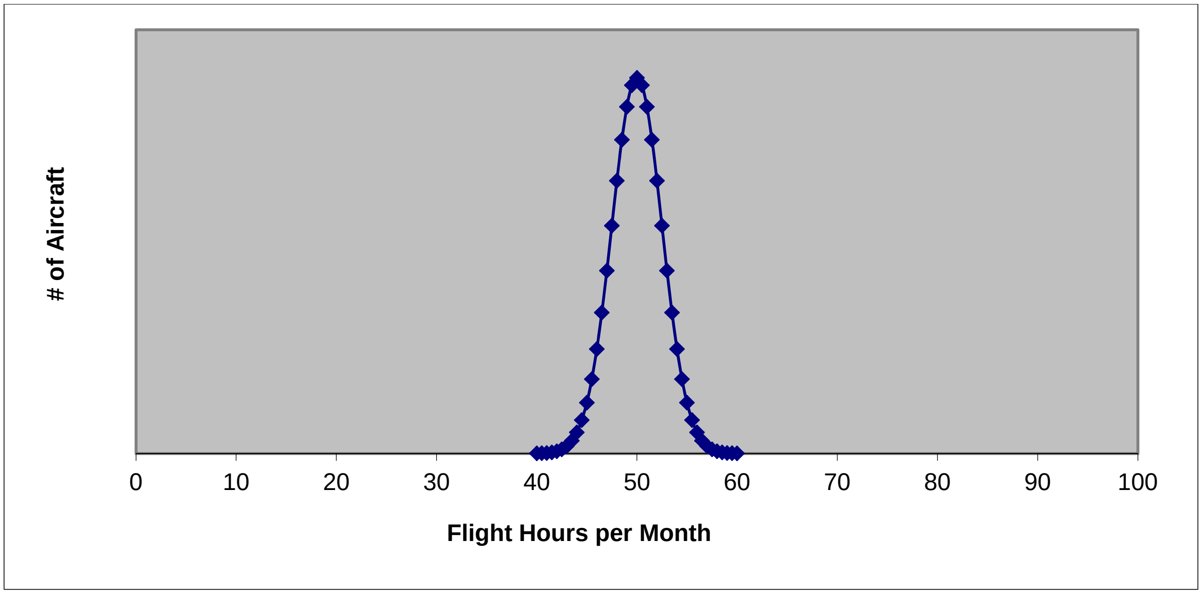


Figure 4-2 Narrow Distribution

Although the distributions differ significantly, the average utilization for both is 50 flight hours per month. In the case illustrated in Figure 4-2, an inspection every 10 months may be adequate. This is due to the relatively consistent utilization of aircraft.

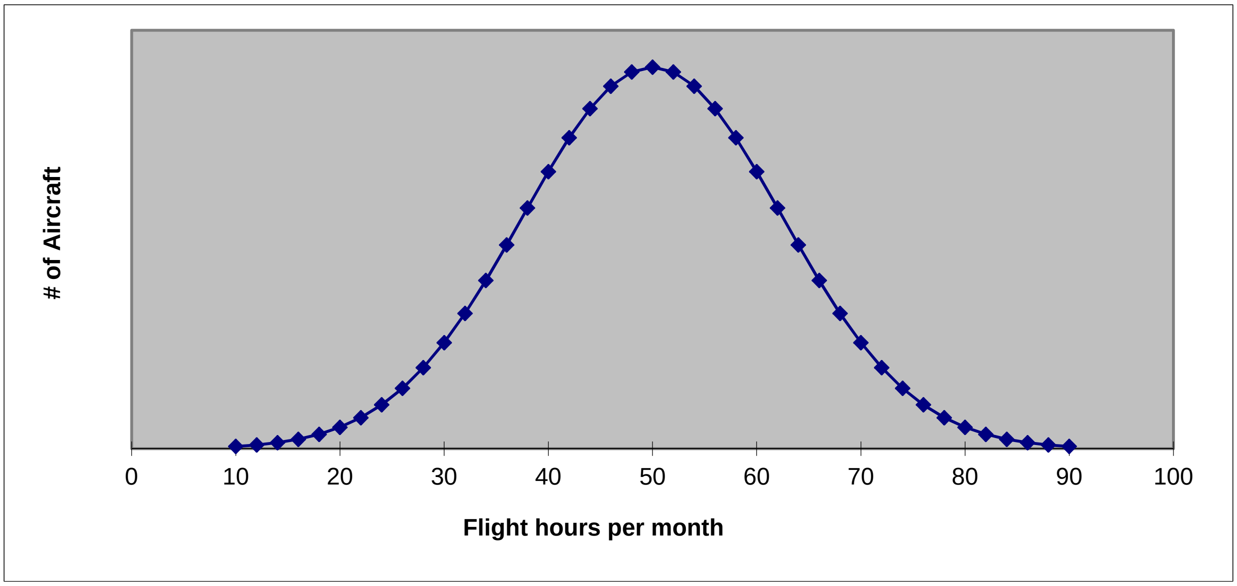


Figure 4-3 Wide Distribution

Conversely, in the case illustrated in Figure 4-3, an inspection every 10 months means that many aircraft will significantly exceed the 500 hour requirement and, in the worst case, one aircraft will fly as long as 900 hours between inspections. In this case, a decision to package the inspection based on a calendar interval is clearly one that has the potential of increasing the probability of failure above an acceptable level.

4.2.1.2 Step 2 - Identify Logical Task Groupings

After the tasks have been laid out on a timeline, identify any natural task groupings that appear to have common inspection intervals, common panel access, and common skill and maintenance levels. Spreadsheets are useful in simplifying this process. Formulating task groupings in this manner will help minimize equipment downtime and reduce the cost of implementing and performing scheduled maintenance. Once the natural groupings have been identified, it is necessary to determine which task(s) are the least flexible in terms of adjustment. In most cases, safety/environmental related tasks dictate where the groups should be packaged. Safety/environmental related tasks can only be performed at intervals that are less than or equal to the interval that was derived from the RCM analysis. Conversely, economic/operational tasks generally can be moved to facilitate desirable packaging. In most cases, optimizing the packaging will offset any loss of efficiency incurred by changing the task interval.

Although not mandatory, it is advisable that packaged intervals be created using multiples of an established base interval. This will help reduce problems in tracking PM tasks by scheduling them to coincide in the proper sequence throughout the entire inspection cycle. Seven days is commonly used as the base interval for tasks designed to address calendar-related failure modes. Hourly inspections are typically done in 50-hour or 100-hour increments. An example of a completed initial packaging effort is illustrated below in Figure 4-4.

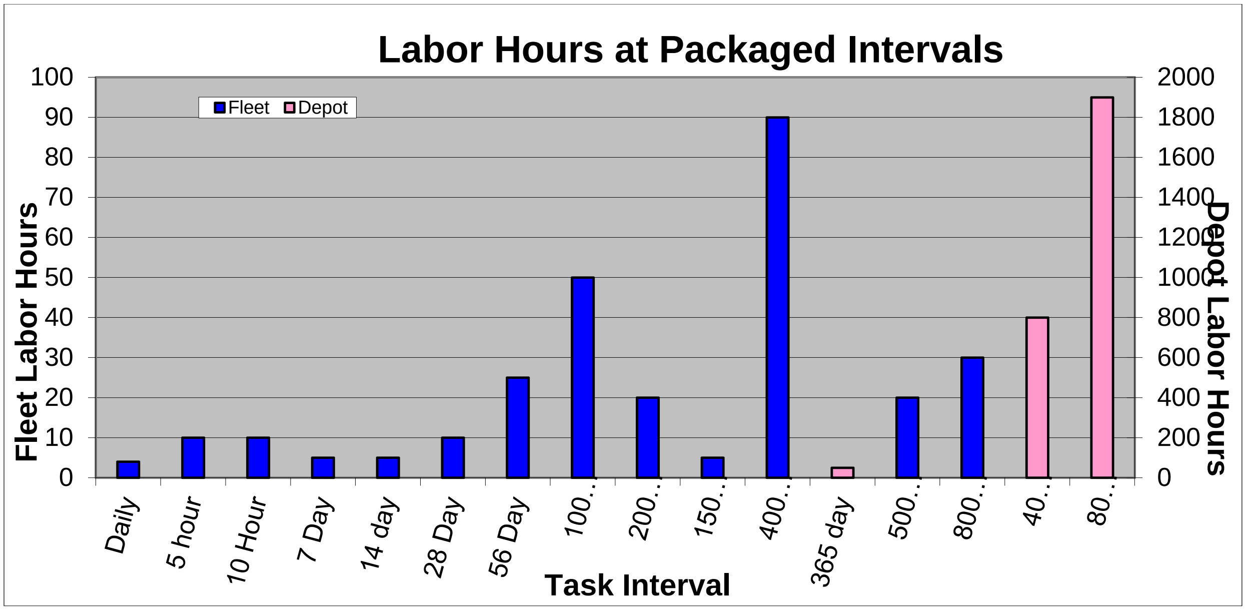


Figure 4-4 Completed Initial Packaging Effort

4.2.1.3 Step 3 – Develop Final Packaging

After the initial grouping of tasks based on frequency and common factors, it may be beneficial to additionally align tasks into "phases" to package the maintenance requirements into more easily accomplished maintenance events. An example of "phasing" maintenance requirements is as follows:

Suppose Tasks 1,2,and 3 are packaged at 100 hours; 4 and 5 at 200 hours; and 6 through 9 at 400 hours. Without phasing, the maintenance packages might be:

100 hours – Tasks 1,2,3

200 hours – Tasks 1,2,3,4,5

300 hours – Tasks 1,2,3

400 hours – Tasks 1,2,3,4,5,6,7,8,9

500 hours – repeat 100 hours package and continue the above cycle

With phasing, the maintenance package might be:

100 hours – Tasks 1,2,3,4,6

200 hours – Tasks 1,2,3,5,7

300 hours – Tasks 1,2,3,4,8 (note Task 4 is repeated at a 200 hour interval)

400 hours – Tasks 1,2,3,5,9 (note Task 5 is repeated at a 200 hour interval)

500 hours – repeat 100 hours package and continue the above cycle (note Tasks 6 through 9 will be repeated at 400 hour intervals)

The above example is a simplistic example of "Phased Maintenance". Often letter codes are assigned to the primary phases (Phase A = 100 hours, B = 200 hours, C = 300 hours, D = 400 hours), which are then repeated throughout the life of the equipment. In reality, additional considerations such as operational impacts, location/access, skill levels, ability to conduct tasks in parallel, elapsed maintenance time, and resource requirements (such as electrical power, hydraulic power, NDI, post-maintenance checks, support equipment, tools) would be considered in developing the phases, but the benefit of "phasing" is to level out the maintenance requirements to reduce operational impact while still preserving the integrity of the period between inspections. Tasks that cannot be fit into the phased maintenance cycles would be handled as "Special Inspections" and scheduled according to their individual periodicity, considering operational impacts and maintenance efficiencies.

Sometimes tasks may be packaged with other maintenance for convenience. If this is done, the underlying RCM derived interval for the tasks must be reviewed to ensure the convenience-oriented packaging will not result in exceeding the interval and resulting in ineffective maintenance. It may be necessary to add a "not to exceed" interval to a requirement that is packaged for convenience to protect the equipment from exceeding a specified period between tasks. Overuse of "convenience-oriented" packaging could also result in excessive maintenance and reduce the benefits gained from performing the RCM analysis to determine the best maintenance frequencies.

Another fairly new concept is "flexible packaging" where requirements are not fit into fixed packages of maintenance tasks, but instead are accomplished in conjunction with maintenance opportunities or downtime events based on the accumulated usage of each individual item. This concept allows maintenance to be performed uniquely for each end item, and therefore requires significant management oversight or facilitization using automated rulesets and tracking to ensure all maintenance is performed across the population before the RCM-derived tasks intervals. While significant operational and economic advantages are possible, the oversight required to ensure safety is not compromised should be carefully considered before adopting this approach. Development of reliable PHM systems will make this kind of approach more easily accomplished. An additional consideration is the need to reliably predict budget, material, and resource requirements when the maintenance packages and intervals are not fixed.

4.2.2 Fitting Tasks Into Existing Packages

For systems with established maintenance programs, it is preferable to package new or updated tasks into the existing maintenance intervals. This tends to minimize, among other things, the impact on maintenance, operational commitments, personnel staffing and training, and publications. However, just as with initial packaging efforts, the impact on task effectiveness must be taken into account when packaging tasks at intervals other than what the RCM analysis recommends.

In many cases, tasks will not fit conveniently into phase maintenance packages, so it is necessary to create special inspections. Examples of special inspections are 7-Day Specials, 14-Day Specials, and 28-Day Specials. If there are large numbers of special inspections, particularly at reasonably long intervals, it may be advisable to revisit the phase interval for a more effective packaging method.

4.2.3 Repackaging

An effective RCM program will include a periodic review of the PM task packages with responsible maintainers and operators to verify that the tasks and packaged intervals are appropriate considering the operational and maintenance scenarios for the equipment. Primary focus should be placed on the individual tasks within the packages, concentrating on their effectiveness at achieving the desired levels of reliability. Poor reliability may be an indication that tasks are ineffective or ill timed. Feedback from these reviews should be used to revisit the original analysis for task rationale and update as necessary, or to re-evaluate the packaging strategies.

4.2.4 Special Considerations for PHM Driven Tasks

While PHM introduces opportunities for detecting failure modes, tracking usage, or finding failures, it also introduces potential complications for maintenance scheduling. Since the maintenance will be "driven" by an indication from monitoring or sensing devices, it must be well understood what is being monitored or sensed to properly plan maintenance. While this guide is unable to cover all possibilities, the following examples will help to illustrate the special considerations necessary when preventive maintenance is driven by PHM systems.

The PHM system may be performing an on-condition inspection where it is detecting a potential failure condition prior to functional failure. The potential failure condition and the time/usage remaining before functional failure must be well understood. To avoid disruption to operations, it may be possible to establish a "time to correction" once the indication occurs to allow planning for corrective action at a more convenient time than immediately upon the indication.

The PHM system may be performing monitoring for a hard time task. The PHM indication of a need for the hard time task should be set to allow time to plan for the task to remove/replace/restore the item, as required, at a convenient maintenance opportunity.

The PHM system may be performing a "failure finding" task. In this case it may not be possible to delay maintenance once the failure is indicated.

Some PHM systems require maintenance personnel to record or download information periodically, run checks, or check outputs. While often done after each usage, some may require longer intervals that must be planned/scheduled. Again, the particular application and parameters must be well understood before deciding on the frequency of these actions.

In all the above examples, once the time for required action is identified, it must be clearly identified in maintenance manuals or programmed into the PHM and maintenance support systems. If possible, the actions should be aligned with the overall preventive maintenance program to avoid unnecessary disruption to operations.

4.2.5 Environmental Considerations

Environmental regulations must be taken into consideration when implementing or modifying maintenance tasks as a result of RCM efforts. New tasks or changes in intervals that result in changes to hazardous material usage or pollutant emissions may require additional authorizations. By adding or increasing the frequency of a maintenance task involving a hazardous material or pollutant emissions, numerous legal ramifications may occur including violations of the National Environmental Policy Act (NEPA), the Clean Air Act, the Clean Water Act, Aerospace National Emissions Standards for Hazardous Air Pollutants (NESHAPs), and various other State, National, or International environmental laws/regulations.

Maintenance related materials that are regulated include, but are not limited to:

- Solvents
- Sealants
- Coatings (Chromated Conversion Coating and Hexavalent Chrome)
- Petroleum, Oil, and Lubricants (POL)
- NDI Materials
- Strip Media - (e.g. Glass Beads)
- Brush Cadmium plating
- Corrosion control materials

Establishing or expanding maintenance capability at facilities where such operations were not previously performed could affect NEPA and may require environmental assessments/ environmental impact statements as well as changes to permits. This most often occurs during establishment of new maintenance programs, such as the Integrated Maintenance Concept (IMC), at operational locations where an increase in procedures such as painting, stripping, and testing could affect the overall environmental quality thus resulting in violations. Failure to comply with environmental law could expose the programs and individuals (including Commanding Officers of the parent and/or tenant commands) to legal action (including possible criminal prosecution).

The following steps are recommended when implementing or modifying maintenance tasks that result in the use of possibly hazardous materials or changes in pollutant emissions.

- Review Material Safety Data Sheets (MSDS). If the material is considered hazardous then the Environmental Safety and Occupational Health (ESOH) coordinators or similar personnel shall be consulted.

- If in doubt, ESOH coordinators or similar personnel shall be consulted for their evaluation and recommendations.
- In the event there is no coordinator assigned, Navy Regional Environmental Coordinators (REC), cognizant materials laboratories, as well as the Lead Maintenance Technology Center - Environment (LMTCE) should be consulted.

Ensure associated handling and disposal costs of the hazardous materials are included in any cost analysis associated with evaluation of the task (including associated repairs), if possible. The costs can be substantial and may affect the determination of frequency or overall cost effectiveness of the failure management strategy.

4.3 IMPLEMENTATION OF OTHER ACTIONS

Implementation of “Other Actions” can be divided into two distinct categories: those that require mandatory action and those that are desirable but not urgently required. While the solutions may be similar for each category, the urgency with which they are dealt differs significantly. Implementation of these Other Actions should be done so in accordance with the program’s operating procedures.

4.3.1 Mandatory Action

When an RCM analysis indicates that the desired reliability of an asset cannot be achieved with a PM task, and allowing the item to fail is unacceptable, some Other Action must be taken. This is particularly true for failure modes whose occurrence will have an adverse affect on safety or the environment. As discussed previously in Section 3.5.9, several options can be used to correct the deficiency. The options include, among others, an item redesign, the incorporation of operating restrictions, or modifying maintenance procedures.

It may be necessary to quickly alleviate an unacceptable condition for items that are in-service. If this is the case, several possible alternative actions may be identified that can potentially correct the problem and achieve the level of reliability required of the item. When the selected alternative action, for example, item redesign, is selected for implementation, and it is determined that it will be a lengthy process, some interim action most likely will be required as a temporary fix. The interim action itself may be one of the options that were determined to be feasible, though less desirable than the primary alternative, but it is one that can be implemented without undue delay. In most cases, the urgency is not as critical for items that have not yet been put into service, so there is more time to implement the desirable primary option.

Final resolution of the appropriate action to be taken must be based on several factors. These include, but are not limited to the cost of the option, the ability to incorporate it, how well it will perform, and the impact it will have on operations. Since the RCM analyst alone will often be unable to make the final determination of the most suitable solution for failure modes requiring

Other Action, the RCM Program Implementation Manager will confer with program management representatives to evaluate the problem and select the appropriate options.

4.3.2 Desirable Action

Some Other Action might be desirable when a PM task cannot be developed that would reduce the consequences of a functional failure that affects operations or economics, but not safety or the environment. In this case, some Other Action is “desirable,” not mandatory. The primary benefit is an economic or operational improvement. All options should be evaluated through a cost-benefit analysis to determine which one offers the greatest return on investment. Among the issues that must be considered are such things as the cost of the options and the ability to incorporate them in a timely manner. Consideration also must be given to the confidence that each option will meet performance expectations and their impacts on operations.

4.4 IMPLEMENTATION OF AE TASKS

Data needed to make informed decisions are often not available when performing an RCM analysis. When this is the case, it becomes necessary to make assumptions. The assumptions are usually set conservatively, which in turn results in conservative PM tasks. Thus, the tasks tend to be less than optimally effective, and, in most cases, they are performed more often than necessary. Age exploration tasks are generally used to collect specific data from actual operational and test environments to replace the assumptions that were made during the initial RCM analysis and PM task development efforts. AE data may reveal the need to extend, shorten or, in some cases, establish or eliminate PM tasks.

The first step in developing an AE task is to define what information is being sought. The desired data may be defined in an Age Exploration Plan (AEP) with as much detail as possible to identify who should perform the data collection and by what means the data should be gathered (see Section 3.5.10.1 for more detail on AEPs). There are two general categories of such data: data that are currently being collected and data that must be collected.

For data that are currently being collected, it is only necessary to define the frequency at which it will be reviewed and the duration of the effort. The following methods are typically employed for this type of AE task:

- Review data from available sources such as the NALDA or depot data.
- Review data for serialized components in equipment history records (EHR) (Direction on the use of an EHR is provided in COMNAVAIRFORINST 4790.2 and NAVAIRINST 4790.3 (series).)

For data that must be collected, it is necessary to set up a task to collect specific data. This includes defining the frequency and duration of the task. The method used to transmit data to the fleet support team or the integrated program team should be defined. The following methods are typically employed for this type of AE task:

∗ Sampling tasks that are carried out in conjunction with D-level maintenance

∗ Data collection through site visits to maintenance activities; verbal communication with maintenance personnel

∗ Age Exploration Bulletins (AEB) - Specific direction for AEBs is given in NAVAIR-00-25-300. This method is used for direct data collection from O-level or contractor maintenance organizations.

Data that are collected via AE tasks should be electronically stored for retrieval and use in future analyses. Digital photographs that illustrate problems or failure data anomalies are extremely beneficial.

4.5 PERFORMING PM TASKS EARLY

Sometimes, the need arises to remove items from operation for some reason other than scheduled maintenance. When this occurs it might be advantageous to perform certain PM tasks even though they will be performed sooner than their established task schedule prescribes. Engines, for example, are frequently reworked significantly once they have been removed, regardless of the reason for removal. This is because the cost and operational impact of removing an engine is too high to forgo the immediate opportunity to perform PM tasks that would otherwise require its removal again at some future date. When an item is removed earlier than scheduled, the maintainer must decide whether a specific PM task, or possibly a group of PM tasks, should be performed in conjunction with the unscheduled repair. The operational and economic ramifications of performing the PM tasks early should be considered when making this decision. To assist in making these decisions, programs should establish guidelines for deciding whether performing PM tasks earlier than scheduled would be beneficial. These guidelines should be a part of the overall maintenance planning process. Several programs have established guidelines using, among others, the following techniques:

∗ Survey item operators to determine the minimum operating time that must be remaining between the unscheduled removal and the scheduled removal that will allow operational commitments to be met. If it is determined that less than the required minimum time remains between the two removal actions, then the PM task, or group of PM tasks, should be performed.

∗ Determine the total cost of performing the PM tasks, including the cost of removing and replacing the item to gain access to the components being inspected or replaced versus the cost to perform the PM tasks early, i.e., to perform the PM tasks in conjunction with the unscheduled repair – avoiding costs to remove, replace, or gain access. If the percentage of time remaining in the PM interval is less than the percentage reduction of the total PM cost by performing the task early, then the PM task, or group of PM tasks, should be performed.

SECTION V

SUSTAINMENT OF RCM PROGRAM

5.1 INTRODUCTION

A failure management strategy and accompanying PM program that is based on the RCM philosophy must be dynamic. This is especially true during the early stages of a new program when it is based on limited information. Maintenance organizations must therefore be prepared to collect, analyze, review and respond to in-service data throughout the operating life of the equipment in order to continually refine the failure management strategy. The procedures and processes used to monitor, analyze, update, and refine the strategy and PM program through RCM analyses will help ensure safe operations and cost-wise readiness. The sustainment approach should be identified in the RCM Program Plan. This dynamic process is depicted in Figure 5-1.

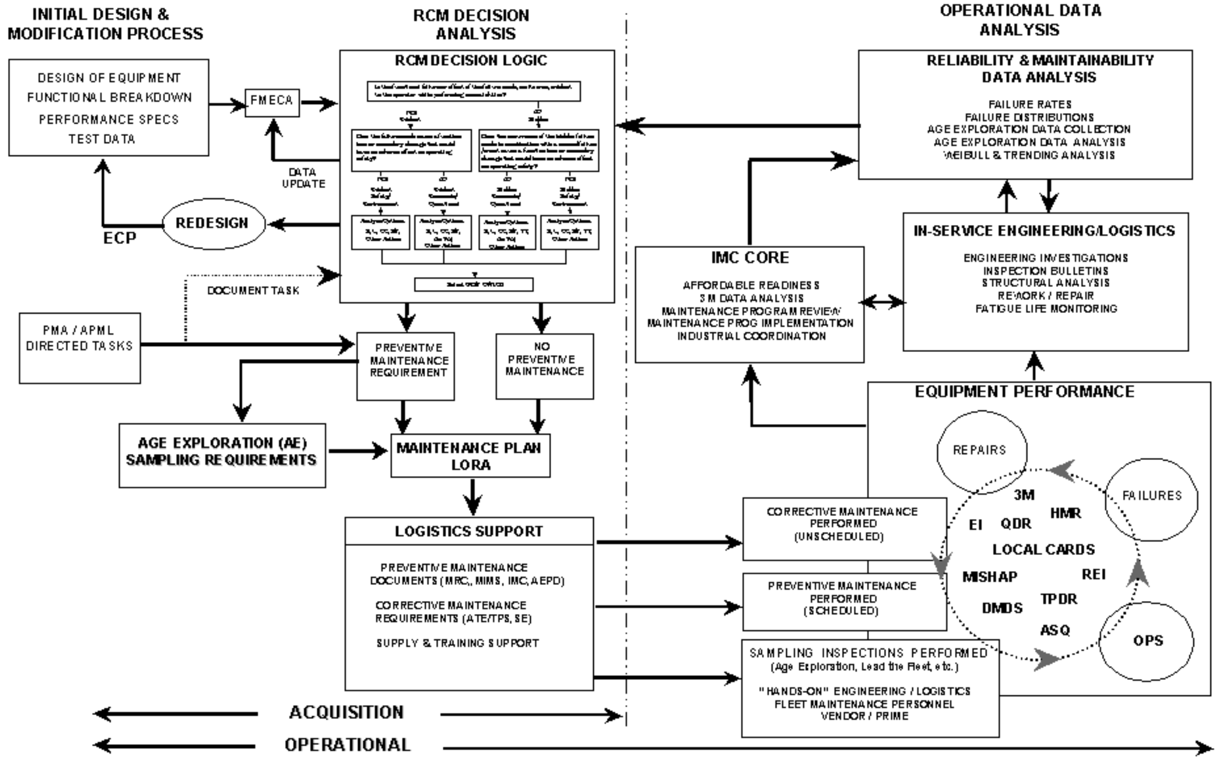


Figure 5-1 RCM Closed Loop Dynamic Process

The basis for the decisions made during an RCM analysis change continuously as the program experiences growth and maturity, which is brought about by time, use, modifications, updates, etc. Review and refinement of the PM program must be an ongoing process, requiring organized information systems that provide a means to conduct surveillance of items under actual operating conditions. The information is collected for two purposes. First, it is used to determine what refinements and modifications need to be made to the initial PM program (including task interval adjustments). Secondly, it is used for collecting data to determine the need for taking some other action, such as product improvement or making maintenance /operational changes.

5.2 SUSTAINING THE ANALYSIS

The objective of the sustainment process is to continually monitor and optimize the current failure management strategy, delete unnecessary requirements, identify adverse failure trends, address new failure modes, and improve the overall efficiency and effectiveness of the RCM and PM programs. Sustainment efforts should be structured such that the results can be effectively used to support RCM analysis updates. The process of monitoring existing maintenance tasks entails reviewing the many sources of task effectiveness information and maintaining accurate and efficient analysis data. The types of efforts used in the RCM sustainment process include Top Degrader Analyses, Trend Analyses, PM Requirements Document Reviews, Task Packaging Reviews, Fleet Leader programs, Age Exploration (AE) tasks, and handling the day-to-day emergent issues.

5.2.1 Top Degrader Analysis

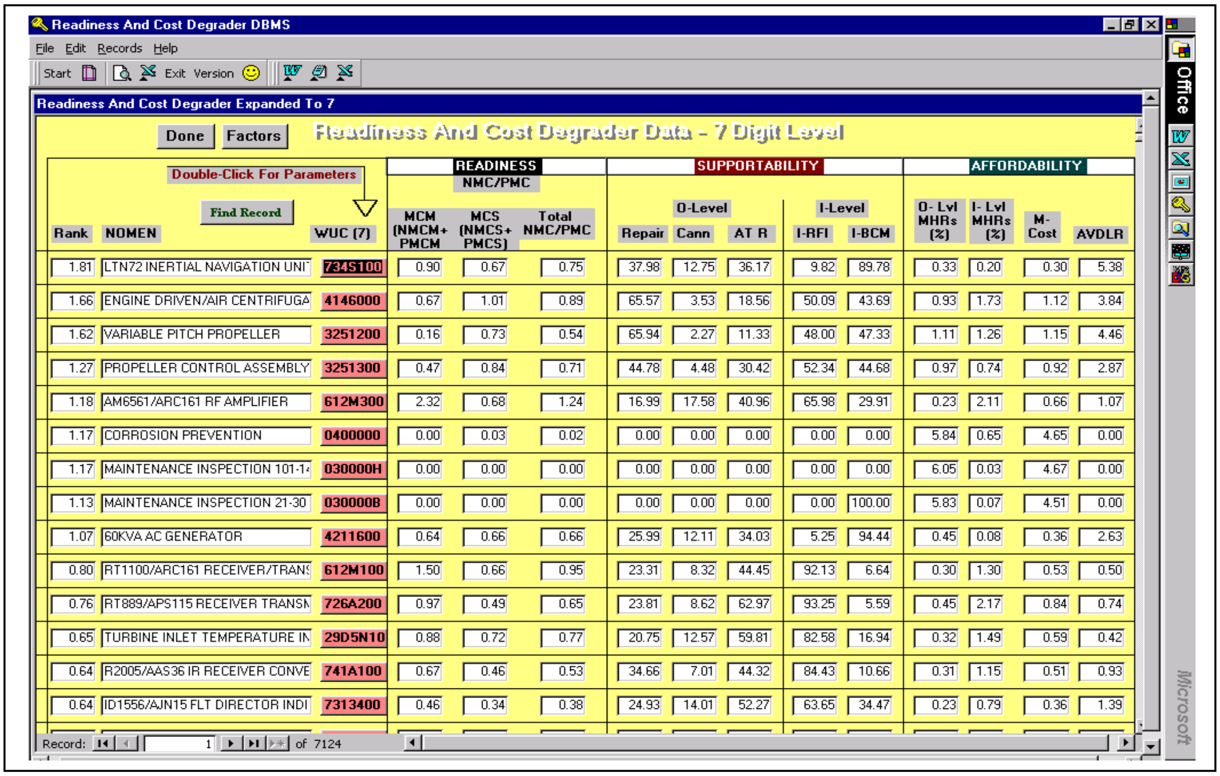
Top degrader ranking indicates which items are having the highest operational or cost impact. Top degrader measurement factors may include the following:

- Maintenance man-hours (MMH)
- Equipment downtime or Not mission capable (NMC)/Partial mission capable (PMC) rates
- Maintenance actions (MA)
- Weapon uploads/downloads
- Aviation Depot Level Repairable (AVDLR) cost
- Consumables cost
- Failures
- Hazard Reports
- Aborts

These parameters are usually normalized to an appropriate operating parameter (such as flight hours) to allow comparison. The identification of top degraders usually entails detailed data analyses, and interface with operators and maintainers. This type of analysis identifies only the current worst performing items, not those that are in the process of degradation. It also does not compare performance to expectations. Some items may appear on a top degrader report because of their nature and use, e.g., tires and brakes. Further analyses of these items may not be necessary. The RCM analyses for items that are deemed problematic should be reviewed and updated as necessary. Figures 5-2 and 5-3 are examples of top degrader reports that were derived from various equipment condition analysis (ECA) reports using NALCOMIS data.

							DEGRADER RANKING						
SUBSYSTEM/ITEM	WUC	FAILURE DESCRIPTION	MOD DECRIPTION	EXISTING MTBF (FH)	NEW MTBF (FH)	FLEET COST	VERIFIED FAILURES DAY/NITE	O/I HR	O HR	BCM	AVDLR	NMCS	PMCS
FUSELAGE DOORS	1121A 111AA 1115A 1112G 1113G	Worn Airloc fasteners and receptacles resulting in extensive maintenance and TFOAs	Replace the existing Airloc fasteners and receptacles with ones with improved retention	63.24	430	2848 1301 1559	3 / 5	18				9	
FUSELAGE HEAT SHIELDS	111AE	Cracking resulting in extensive maintenance repair	Redesign increases thickness and remove stress concentrations	101.86	1000	17773	4 / 2	16	9			9	
BRU36A BOMB RACK	754CJ	Corrosion on numerous components resulting in jamming	Replace with the more reliable F-18 BRU-32 Bomb Rack	58.21	400	6015	3 / 10	23	14				
CANOPY OPEN/CLOSE MECHANISM	11267	Worn rollers, latches and mechanism resulting in in-flight openings	Redesign with improved materials and tolerances	121.27	500	18640	8 / 14	14	15				

Figure 5-2 Example Top Degrader Analysis



Readiness And Cost Degrader Expanded To 7

Readiness And Cost Degrader Data – 7 Digit Level

			READINESS NMC/PMC			SUPPORTABILITY					AFFORDABILITY			
						O-Level			I-Level					
Rank	NOMEN	WUC (7)	MCM (NMCM+ PMCM	MCS (NMCS+ PMCS)	Total NMC/PMC	Repair	Cann	AT R	I-RFI	I-BCM	O- Lvl MHRs (%)	I- Lvl MHRs (%)	M-Cost	AVDLR
1.81	LTN72 INERTIAL NAVIGATION UNI	734S100	0.90	0.67	0.75	37.98	12.75	36.17	9.82	89.78	0.33	0.20	0.30	5.38
1.66	ENGINE DRIVEN/AIR CENTRIFUGA	4146000	0.67	1.01	0.89	65.57	3.53	18.56	50.09	43.69	0.93	1.73	1.12	3.84
1.62	VARIABLE PITCH PROPELLER	3251200	0.16	0.73	0.54	65.94	2.27	11.33	48.00	47.33	1.11	1.26	1.15	4.46
1.27	PROPELLER CONTROL ASSEMBLY	3251300	0.47	0.84	0.71	44.78	4.48	30.42	52.34	44.68	0.97	0.74	0.92	2.87
1.18	AM6561/ARC161 RF AMPLIFIER	612M300	2.32	0.68	1.24	16.99	17.58	40.96	65.98	29.91	0.23	2.11	0.66	1.07
1.17	CORROSION PREVENTION	0400000	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.00	5.84	0.65	4.65	0.00
1.17	MAINTENANCE INSPECTION 101-1	030000H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.05	0.03	4.67	0.00
1.13	MAINTENANCE INSPECTION 21-30	030000B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	5.83	0.07	4.51	0.00
1.07	60KVA AC GENERATOR	4211600	0.64	0.66	0.66	25.99	12.11	34.03	5.25	94.44	0.45	0.08	0.36	2.63
0.80	RT1100/ARC161 RECEIVER/TRAN	612M100	1.50	0.66	0.95	23.31	8.32	44.45	92.13	6.64	0.30	1.30	0.53	0.50
0.76	RT889/APS115 RECEIVER TRANS	726A200	0.97	0.49	0.65	23.81	8.62	62.97	93.25	5.59	0.45	2.17	0.84	0.74
0.65	TURBINE INLET TEMPERATURE I	29D5N10	0.88	0.72	0.77	20.75	12.57	59.81	82.58	16.94	0.32	1.49	0.59	0.42
0.64	R2005/AAS36 IR RECEIVER CONVE	741A100	0.67	0.46	0.53	34.66	7.01	44.32	84.43	10.66	0.31	1.15	0.51	0.93
0.64	ID1556/AJN15 FLT DIRECTOR INDI	7313400	0.46	0.34	0.38	24.93	14.01	52.27	63.65	34.47	0.23	0.79	0.36	1.39

Figure 5-3 Excerpt from Readiness and Cost Degrader Database

5.2.2 Trend Analysis

A trend analysis provides an indication of systems or components that may be problems currently or in the future. The measurement factors used for trending may be the same as those used for top degraders. When performing trend analyses, however, it is the change in value, rather than the values themselves, which is important. Trend analyses are particularly useful for sustaining RCM because they compare expectations/predictions used during the analysis to actual in-service performance, allowing adjustments and re-analysis when appropriate.

Trend analyses may be performed using statistical measures such as mean and standard deviations to establish performance baselines and comparing current performance levels to established control levels. Performance parameters can then be monitored to identify and investigate the causes of those that exceed the control limits. After the problem has been characterized, the related RCM analysis should be reviewed and updated as necessary. Other corrective action should also be considered, to alleviate the causes of performance deviations. An example of trending analysis is shown in Figure 5-4.

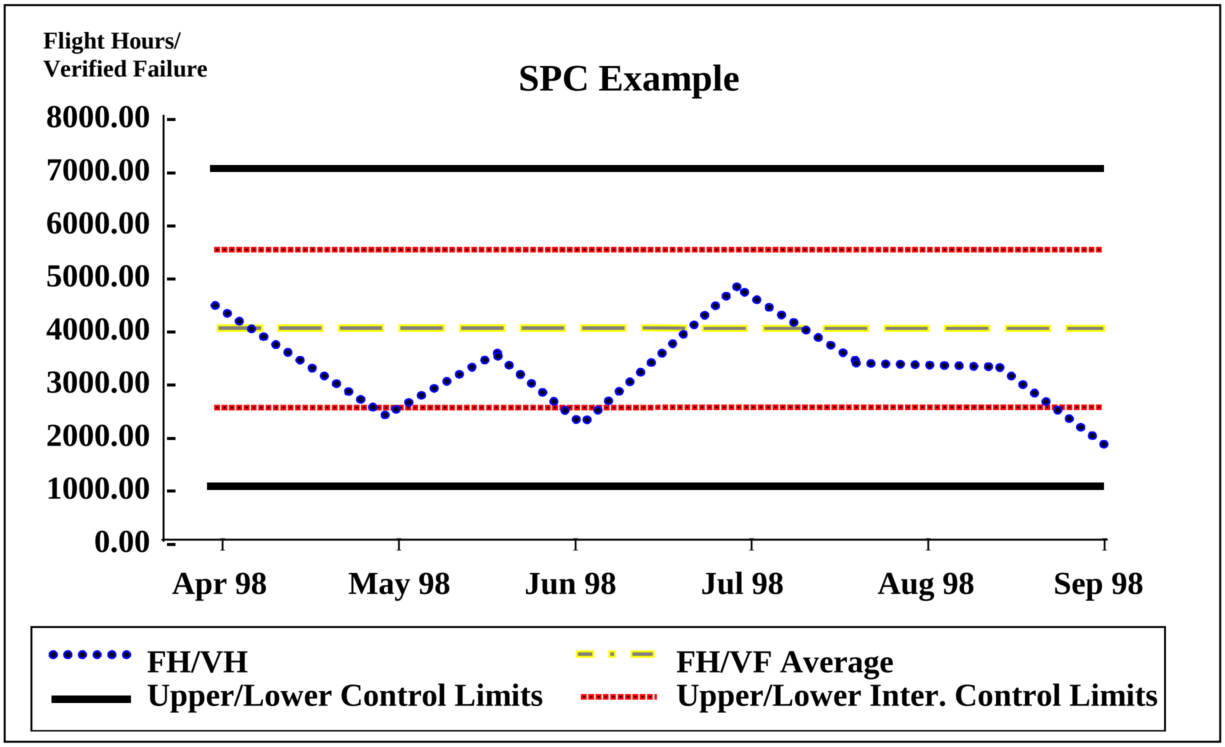


Figure 5-4 Example Top Degrader Trending Analysis

5.2.3 PM Requirements Document Reviews

A review of documents that contain PM requirements should be accomplished periodically to reveal outdated maintenance processes, techniques or technologies, or to bring attention to obsolete tools and outdated supplies. Document reviews provide opportunities to update PM requirements that will improve effectiveness or lower lifecycle costs. Examples of opportunities afforded by this type of review include incorporating new non-destructive inspection techniques or applying advanced PHM sensor technology that detects smaller flaws or monitors growth rates allowing longer (or possibly eliminating) periodic inspection intervals. Other examples include replacing older technology materials, such as paints or sealants, with less environmentally hazardous or less expensive ones reducing maintenance costs. Issues affecting material selection should be coordinated with and supported by local materials laboratory personnel. Fleet representation should be included in document reviews to address ineffective maintenance tasks and current or emergent issues that have been identified.

The following types of documents should be reviewed:

- Maintenance Requirement Cards (MRCs)
- Depot Level Maintenance Specifications
- Maintenance instruction manuals, (for PM requirements that accompany or rely upon corrective maintenance tasks)

An often overlooked element of an RCM program is the correlation of the assumptions made during the PM program development, and the policies and processes used for corrective maintenance. For example, if a PM task was developed utilizing a potential failure condition that was later identified as acceptable damage requiring no repair or monitoring in the maintenance manual, the task interval developed by the RCM process will be compromised. Another example would be a hard time task developed assuming replacement of a sub-component during the repair/overhaul process, when a subsequent change to the item's maintenance/overhaul process allows the sub-component to be reused. Procedures to ensure review by RCM personnel of changes to maintenance procedures are critical to ensuring these kinds of conflicts are prevented. The methodolgy and requirements for these reviews should be included in the RCM Program Plan.

5.2.4 Task Packaging Reviews

Task packaging is the process of incorporating a number of PM tasks, each of which has a discrete engineering interval, into optimum intervals or opportunities, such as a 550-hour phase inspection or 56-day corrosion cycle. When PM tasks are modified and updated, they are often placed back into the same set of packaged requirements/intervals, with minimal review for optimization. As task changes accumulate or operating/maintenance conditions change, the original set of packaged requirements/intervals may no longer be optimal. Task packaging reviews should be conducted periodically to evaluate the packaged requirements/intervals to ensure that as maintenance tasks are added, deleted, or modified, they remain an effective package in the operating/maintenance environment.

Programs that may have chosen "flexible packaging" concepts are particularly vulnerable to creating significant impacts to the maintenance/operating environment or compromising performance of tasks if close attention to the execution of the tasks is not maintained. Review of the methods, rules, and adherence to underlying periodicity requirements of the PM tasks should be a regular occurrence for these programs.

5.2.5 Fleet Leader Programs

A fleet leader program is used to detect the onset of system or component failures that were not expected to occur based on the original reliability predictions. Fleet Leader requirements may be established when the consequences of failure are severe, and experiential data is limited. A more recent example of Fleet Leader inspections may be physical verification of equipment condition protected by PHM systems to ensure the PHM system is properly predicting true equipment condition. The objective of Fleet Leader Programs is to identify specific problem areas and to periodically inspect these areas on one or more “fleet leader,” or most used assets. The fleet leader program may also include specific AE tasks. Appropriate sample sizes should be established to support conclusions desired, based on valid statistical techniques.

Specific requirements for this program should be developed as RCM analyses are completed. Fleet leader inspections should first consider using "opportunity" inspections. For example, FST engineers may participate on a “not to interfere” basis with the first phase inspection of the first one or two aircraft to reach multiples of 1000 flight hours. If the fleet leader task is accomplished in conjunction with depot maintenance, it may be supported by regular visits to the depot line by FST personnel. Fleet Leader inspections may be documented as "Age Exploration" tasks within IRCMS.

5.2.6 Age Exploration Tasks

An AE task may be designed and implemented when insufficient data necessitated the use of assumed data during an initial RCM analysis. AE task data are fed back to the analyst for use in updating the RCM analysis. The requirements for AE tasks become evident during the RCM analysis. AE is covered in detail in Section 3. The RCM Program Plan should provide guidance for implementing AE tasks.

5.2.7 Emergent Issues

An RCM program must establish a process to deal with emergent issues and unpredicted events, and determine the appropriate response or corrective action. Emergent issues may need to be analyzed via the RCM process. An example of such a process is shown in Figure 5-5.

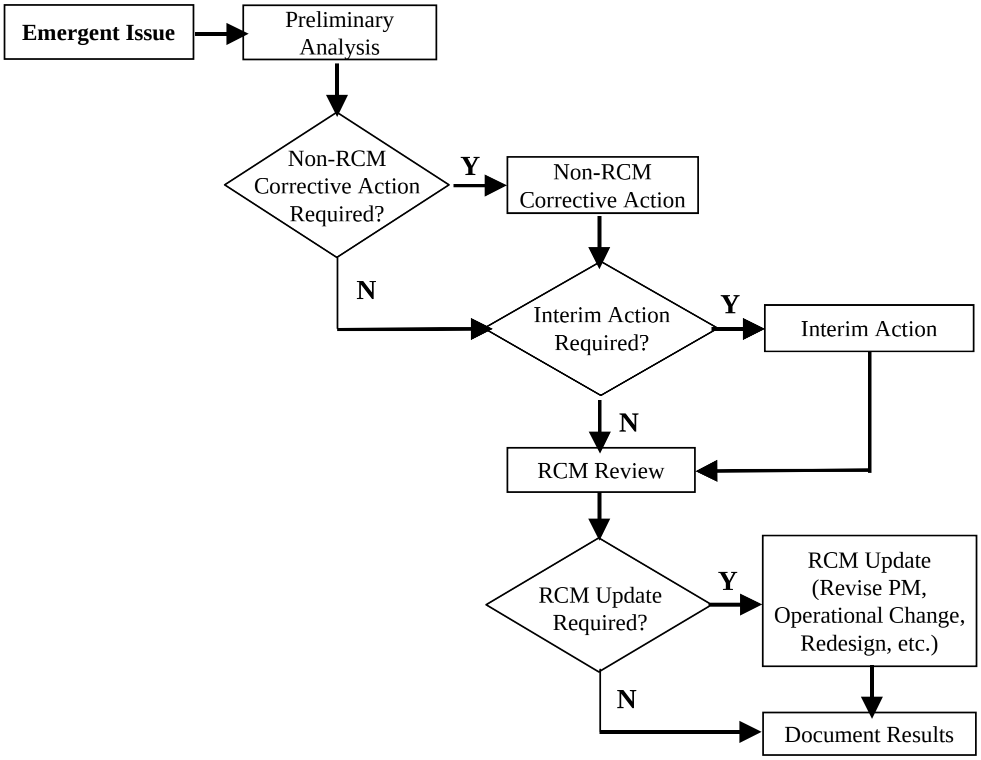


Figure 5-5 Example of Process to Address Emergent Issues

5.2.7.1 Problem Assessment

The cause of the emergent issue needs to be identified. Performing engineering investigations and conducting interviews with maintainers and operators are examples of methods of assessing problems.

5.2.7.2 Non-RCM Corrective Action

The emergent issues may be addressed by corrective actions for which an RCM analysis is not required. Technical publication changes and design changes are examples of non-RCM corrective actions.

5.2.7.3 Interim Action

The preliminary analysis may sometimes reveal problems that may need immediate attention due to safety concerns or other programmatic requirements. Examples of interim actions include issuing inspection bulletins, applying temporary operational restrictions, and implementing operating safety measures.

5.2.7.4 RCM Review

The results produced from reviewing an RCM analysis will be a factor that should be considered in determining a response to that problem. Therefore, it is imperative that an RCM review be part of the overall methodology. The RCM review and update, if necessary, will determine if changes in the failure management strategy or PM requirements are necessary. It will aid in determining if one-time inspections (bulletin), redesigns (ECP), maintenance process changes, or other corrective actions are necessary. Decisions not to update the RCM analysis should be documented for audit purposes. The RCM review should address questions such as the following:

- Is the failure mode already covered?
- Are the failure consequences correct?
- Is the reliability data accurate?
- Is the existing task (or requirement for no task) adequate?
- Are the related costs accurate?

5.2.7.5 RCM Update

The RCM analysis should be updated when new failure modes or failure modes previously thought unlikely to occur are determined to be significant. The existing analysis for a failure mode may also be determined to be incorrect or inadequate. Inadequate analyses can result for any number of reasons, such as revision of mission requirements or changes to operator or maintainer procedures.

5.2.7.6 Sources of Emergent Issues

Several sources are available from which emergent issues can be identified. These include, among others, the following:

- Defect Reports – This process historically has been the primary responsibility of maintenance engineering activities. In addition to RCM analyses, other analyses and investigations must be performed. While not formally part of the RCM process, these analyses and investigations are related to the RCM process.

- * Failures and other problems are reported through various means, each requiring a specific type of response. Examples include requests for engineering investigations (EI), Hazardous Material Reports (HMR), Quality Deficiency Reports (QDR), Technical Publications Deficiency Reports (TPDR), and mishap investigation reports. Specific requirements for each process are provided in COMNAVAIRFORINST 4790.2 (series) and OPNAVINST 8000.16 (series).
- * Depot Discrepancy Reports – Defects discovered during Depot level inspections are provided in the form of Depot Level Maintenance discrepancy reports or other reporting processes. All scheduled and unscheduled D-level inspections and rework/overhaul efforts should provide feedback to the RCM process.
- * Vendor and Original Equipment Manufacturer (OEM) Discrepancy Reports – All scheduled and unscheduled vendor and OEM inspections and rework or overhaul efforts should provide feedback to the RCM process. Special effort may be required to obtain this data through contractual actions, vendor visits, etc.
- * Local Maintenance Requirement Cards (MRC) – In accordance with COMNAVAIRFORINST 4790.2 (series), operating activities are required to submit locally-generated MRCs to FST personnel for assessment. All local MRC recommendations should be justified via the RCM decision logic process before fleet-wide implementation.
- * RCM Updates Due to Design Changes – Design changes may be driven by a variety of factors including a redesign decision from the RCM logic. Regardless of whether or not a design change is driven by RCM analysis, a review and update of the analysis may be required. The design change, which may be in the form of a single item change or a major system modification, will be implemented through the ECP process. An assessment of the impact on supportability should be an integral part of the maintenance planning efforts of any proposed design change. RCM analysis reviews or updates should be accomplished as part of the design change process in order to assess any impact on the maintenance program.
- * RCM Updates Due to Test Results – Results of tests such as fatigue tests, certification tests, and test performed during item failure investigations may require RCM review and update in much the same manner as in-service failures. Test data may also be used in the course of an RCM review or update that was initiated by some other event.
- * If tests are initiated to extend the service life of assets, an RCM analysis update is required to implement the changes resulting from the tests. These results may affect not only the item under test, but might extend to other items if the overall service life of the asset or end item is extended beyond the assumptions made in the original analysis.

5.3 RESULTS OF SUSTAINING EFFORTS

The sustaining efforts discussed above may require changes to the RCM analysis resulting in a changed or modified failure management strategy. Possible changes include adjusting maintenance intervals, modifying PM task procedures, and modifying AE tasks. Other changes that might result from these sustaining efforts include, for example, redesign recommendations, maintenance process changes, or operational restrictions.

If it is found that an existing maintenance task is not being performed at the most effective interval, information collected through sustaining efforts may provide the data needed to refine the assumptions that were used to establish the interval during the initial RCM analysis. By applying the new data to the RCM analysis, the PM task interval can be adjusted to improve its effectiveness.

Sustaining efforts may also identify the need to add, delete, or modify PM tasks. This could be, for example, changing an inspection method or material, adding or deleting requirements, or changing the type of PM task altogether, e.g., going from an On Condition inspection to a Hard Time removal. The results should be used to update the RCM analysis to accomplish these changes.

Sustaining efforts may also generate a requirement to modify AE tasks that are in place. The task modification may be as simple as changing the number of samples which will undergo analysis or as complex as rewriting the inspection task and data recording process. An effective RCM program will necessarily impose frequent change to the AE program, such as adding new AE candidates, deleting completed or unproductive tasks, changing sample sizes, or adjusting task intervals.

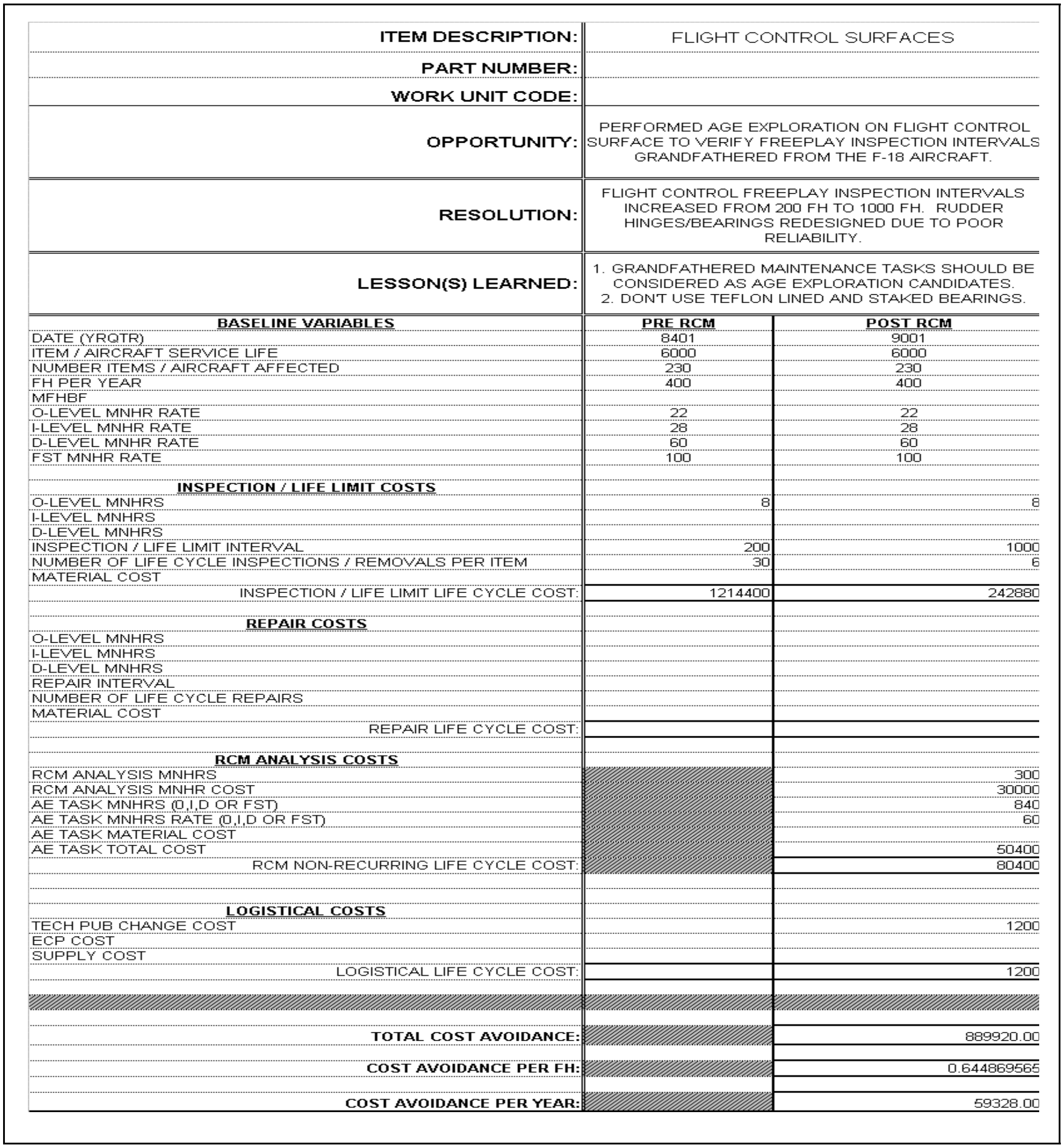
5.4 ASSESSMENT OF RCM PROGRAM EFFECTIVENESS

The essential performance metrics identified in the RCM Program Plan should be monitored to measure the effectiveness of the RCM Program. The RCM analyses should have established the units of performance measurement for the items under evaluation. For example, if an RCM analysis assumes that bearing wear is a function of operating cycles, it would be prudent to track failures or removals as a function of operating cycles during the sustaining analyses.

The feedback from effectiveness assessments can be used to provide justification for the continued application of RCM to appropriate program managers and higher authorities. Examples of effectiveness metrics are cost avoidance, maintenance performed, and operational readiness.

5.4.1 Cost Avoidance

Cost avoidance compares the operational cost related to the original maintenance or reliability of an item with the operational cost that result after the application of an RCM analysis. The RCM analysis may offer any of several alternative solutions. For example, it could recommend the addition of a new task or deletion of the existing PM task. Additionally, substantial cost avoidance could be realized by optimizing the existing task by adjusting the interval, modifying the procedure, or recommending a redesign. An example of the documentation used when assessing cost avoidance is shown in Figure 5-6.



ITEM DESCRIPTION:	FLIGHT CONTROL SURFACES
PART NUMBER:	
WORK UNIT CODE:	
OPPORTUNITY:	PERFORMED AGE EXPLORATION ON FLIGHT CONTROL SURFACE TO VERIFY FREEPLAY INSPECTION INTERVALS GRANDFATHERED FROM THE F-18 AIRCRAFT.
RESOLUTION:	FLIGHT CONTROL FREEPLAY INSPECTION INTERVALS INCREASED FROM 200 FH TO 1000 FH. RUDDER HINGES/BEARINGS REDESIGNED DUE TO POOR RELIABILITY.
LESSON(S) LEARNED:	1. GRANDFATHERED MAINTENANCE TASKS SHOULD BE CONSIDERED AS AGE EXPLORATION CANDIDATES. 2. DONT USE TEFLON LINED AND STAKED BEARINGS.

BASELINE VARIABLES	**PRE RCM**	**POST RCM**
DATE (YRQTR)	8401	9001
ITEM / AIRCRAFT SERVICE LIFE	6000	6000
NUMBER ITEMS / AIRCRAFT AFFECTED	230	230
FH PER YEAR	400	400
MFHBF		
O-LEVEL MNHR RATE	22	22
I-LEVEL MNHR RATE	28	28
D-LEVEL MNHR RATE	60	60
FST MNHR RATE	100	100
INSPECTION / LIFE LIMIT COSTS		
O-LEVEL MNHRS	8	8
I-LEVEL MNHRS		
D-LEVEL MNHRS		
INSPECTION / LIFE LIMIT INTERVAL	200	1000
NUMBER OF LIFE CYCLE INSPECTIONS / REMOVALS PER ITEM	30	6
MATERIAL COST		
INSPECTION / LIFE LIMIT LIFE CYCLE COST:	1214400	242880
REPAIR COSTS		
O-LEVEL MNHRS		
I-LEVEL MNHRS		
D-LEVEL MNHRS		
REPAIR INTERVAL		
NUMBER OF LIFE CYCLE REPAIRS		
MATERIAL COST		
REPAIR LIFE CYCLE COST:		
RCM ANALYSIS COSTS		
RCM ANALYSIS MNHRS	▨	300
RCM ANALYSIS MNHR COST	▨	30000
AE TASK MNHRS (0,I,D OR FST)	▨	840
AE TASK MNHRS RATE (0,I,D OR FST)	▨	60
AE TASK MATERIAL COST	▨	
AE TASK TOTAL COST	▨	50400
RCM NON-RECURRING LIFE CYCLE COST:	▨	80400
LOGISTICAL COSTS		
TECH PUB CHANGE COST		1200
ECP COST		
SUPPLY COST		
LOGISTICAL LIFE CYCLE COST:		1200
▨	▨	▨
TOTAL COST AVOIDANCE:	▨	889920.00
COST AVOIDANCE PER FH:	▨	0.644869565
COST AVOIDANCE PER YEAR:	▨	59328.00

Figure 5-6 Example of a Cost Avoidance Document

5.4.2 Maintenance Performed

The man-hours expended in performing scheduled and unscheduled maintenance may provide an indication of the maintenance program's effectiveness. Comparison of man-hours consumed prior to implementation of RCM-generated PM tasks with man-hours used afterward may identify opportunities for improving the program.

5.4.3 Operational Readiness

The availability of the end item may be an indication of the effectiveness of the RCM-generated maintenance tasks. Items that had been operating without benefit of PM may have required extensive unscheduled (corrective) maintenance, which significantly impacted availability. Other items may have been "over maintained," also impacting availability. Compare the readiness of the end item before and after implementation of RCM-generated tasks to determine the effectiveness of the changes.

5.4.4 Other Parameters

A review of other parameters before and after a change generated by the RCM program may provide an indication of its effectiveness. Some of these parameters may include unscheduled removal rates, abort rates, and BCM rates.

APPENDIX A

RCM METHODS

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1.1 INTRODUCTION

Various methods are available for meeting the quantitative and qualitative needs of the RCM analysis process. Some methods are widely accepted, while others are applicable only under certain circumstances or applications. Additionally, some methods that were previously used have been found to be suspect after review. Care must be taken to ensure that any method adopted for performing RCM analysis is appropriate, and that any mathematical or statistical methodology is consistent with the data inputs or assumptions used. No method or formula should be used unless there is a clear understanding of their derivations and of the appropriate data or assumptions that must be made for them to be valid. The following RCM methods have been developed for computing or estimating task intervals for the various types of RCM tasks. These methods have been reviewed and are endorsed by the NAVAIR RCM Steering Committee for use in applications where appropriate. Other methods may be found at the NAVAIR RCM web site or by contacting the Steering Committee. It is the responsibility of the user to determine the appropriateness of a given method to a specific application. Programs are encouraged to submit additional methods found helpful in conducting the analysis to the Steering Committee via the NAVAIR RCM web site.

1.2 ON CONDITION TASK INTERVAL DETERMINATION

1.2.1 Using Acceptable Probability of Failure and Task Effectiveness

On Condition task intervals are usually based on some fraction of a potential failure to functional failure (PF) interval. One method of determining an On Condition task interval is based on the premise that any inspection will not be 100% effective. When acceptable probability of failure is the basis for an on-condition task interval (such as for safety and environmental failure modes), it will require some number of inspections over the PF interval to ensure that the probability of failure is reduced to an acceptable level. Shown mathematically:

NOTE:

> **In some cases the following equation will require modification due to the continuous operation of a system (i.e., the inspection is performed while the equipment is operating), or the inability to take corrective action immediately upon recognition of the potential failure. In these cases, time must be allotted to the time shut down the system (or make it available) prior to having the ability to repair the potential failure. This will be referred to as the "time to correct" or deferral time (T_C), and the equation is modified to: $I=(PF-T_C)/n$. This should only be used when the equipment will be used unrestricted or unmonitored following the recognition of a potential failure condition, prior to repair.**

Equation (1) $$I = PF/n$$

Where:

I = Inspection interval

PF = Potential failure to functional failure interval

n = Number of inspections in the PF interval

Assigning an acceptable probability of failure to detect a potential failure condition (and therefore expose the item to functional failure) yields a second equation that can be used to determine n.

Equation (2) $$n = \ln (P_{acc}) / \ln (1-\theta)$$

Where:

I = Inspection interval

θ = Probability of detecting a potential failure with one occurrence of the proposed On Condition task, assuming the potential failure exists

P_{acc} = Acceptable probability of failure

The derivation for this method is as follows:

If θ is the probability of detecting a potential failure in one inspection, assuming the potential failure exists, the probability of not detecting it is $(1 - \theta)$. The probability of not detecting the potential failure in n inspections is $(1 - \theta)^n$. The intent of the task is to reduce probability of missing the potential failure to an acceptable level, P_{acc}. The P_{acc} is that established for a single failure mode. (For hidden failures, the acceptable probability of failure will be based on the probability of the failure/event that makes the hidden failure evident. Therefore P_{acc} of the hidden failure equals the P_{acc} established for the critical failure (i.e., for the multiple failure/demand event) divided by the probability of the protected failure or demand event)

Described mathematically: $P_{acc} = (1 - \theta)^n$. Solving for n yields equation (2) above.

NOTE:

Recognize this equation is not precise in that it calculates the P_{acc} based on the assumption the potential failure exists. This is a conservative assumption and encourages the use of highly reliable inspection techniques. If a more precise interval were desired, the actual failure rate and failure mechanism and distribution would need to be considered in more detail. However, as more precision is pursued, the loss of conservatism must be weighed against the confidence in the data sources to ensure adequate levels of protection against failure are maintained. If more precision is attempted, the analyst must also consider, when establishing the acceptable levels of probability at the end item level, that there are usually multiple safety/environmental consequence failure modes.

This method is appropriate for failure modes with safety/environmental and hidden safety/environmental consequences. It may also be used to provide an estimated value for n for non-safety consequences provided an acceptable probability of failure is identified. However, for economic failure modes an additional step to ensure that the task is cost-effective must be performed as follows:

$$C_{pm} + C_{cm} < C_{nopm}$$

Where:

C_{pm} = Cost of the preventive maintenance program

C_{cm} = Cost of corrective maintenance with preventive maintenance in place considering the potential and functional failures that will occur

C_{nopm} = Cost of correcting functional failures as they occur without the preventive maintenance program in place

1.2.2 Optimizing Task Intervals for Failure Modes with Non-Safety Consequences

Another method for determining the number of inspections, n, in the potential failure to functional failure interval for failure modes with non-safety consequences is to use a cost optimization formula such as the following:

$$n = \frac{ln\left[\dfrac{\dfrac{-MTBF}{PF}Ci}{(Cnpm - Cpf)\ ln\ (1-\theta)}\right]}{ln\ (1-\theta)}$$

Where:

PF = Potential failure to functional failure interval

C_I = Cost of one preventive maintenance task

= (DMMH for inspection) (Labor Cost per hour) + Consumable cost

C_{pf} = Cost of correcting one potential failure

= (DMMH to correct potential failure) (Labor Cost per hour) + Spares and Material costs

C_{npm} = Cost of not doing preventive maintenance

= $C_{cm} + C_{opc}$

Note

If C_{npm} is equal to C_{pf}, there is no benefit in discovering potential failure before functional failure.

C_{cm} = Cost of corrective maintenance

= (DMMH for repair) (Labor Cost per hour) + (Spares and material costs)

C_{opc} = Costs due to operational impact (if established). (If not easily defined, one method to quantify this impact is to divide lost operational time due to unscheduled repair of functional failures by total planned operational time (e.g., divide unscheduled downtime hours by total planned available hours) and multiply by the acquisition cost of the end item.)

θ = Probability of detecting a potential failure with the proposed On Condition task, assuming the potential failure exists

If the solution to the above equation shows $n \leq 0$, it is not cost effective to perform an On Condition task to address the failure mode under evaluation. If $n \geq 1$, divide the PF by n to determine the appropriate task interval. If $0 < n < 1$, the minimum cost effective task interval is obtained by setting $n = 1$ and PF becomes the task interval.

The above equation should be used carefully since it is built on the assumption that each potential failure prevents one functional failure. If the equation is being used to evaluate a task that is expected to result in repeated potential failure repairs to prevent one functional failure, the cost of all repaired potential failures for each functional failure must be considered. Failure to do so will invalidate the equation and promote implementation of tasks that are not cost effective.

1.2.3 Methods for Estimating Potential-to-Functional (PF) Interval

Various methods may be used to estimate PF intervals, including engineering judgment, maintenance and operating personnel input, test and engineering data, material properties, and statistical methods using maintenance and operations data. One method that has been used to estimate the PF interval is to utilize findings from an existing On Condition task.

If an existing task is effective at finding potential failures and preventing functional failures, it may be reasonable to conclude the PF interval is significantly longer than the current inspection interval. Discussion with maintenance and operational personnel, evaluation of the inspection technique (to estimate probability of detection), and review of maintenance data (to determine how far into the failure/degradation process the potential failures have progressed) will aid in establishing the estimated PF. Once the PF is determined, the above methods can be used to set the inspection interval. However, care should be taken not to be overly conservative in estimating the PF such that the new task interval is significantly shorter than an existing effective task, without justification.

If an existing PM task is less effective than desired (i.e., more than an acceptable number of functional failures have occurred with the current task in place), and that task is being considered for continued use, an estimate of PF can be made from the current task interval. However, this method requires significant in-service data on potential and functional failures found, to determine the current task's effectiveness, as follows:

If PF is expected to be longer than the existing inspection interval, PF can be estimated by the following:

$$PF = (\mathit{ln}(1 - \alpha) / \mathit{ln}(1-\theta)) * I$$

When PF expected to be shorter than the existing inspection interval, the formula becomes:

$$PF = (\alpha / \theta) * I$$

NOTE:

If the first equation is used, and PF is determined to be shorter than I, consider whether θ may be less effective than estimated and recalculate, or recalculate PF using the second equation. If the second equation is used, and PF is determined to be longer than I, consider whether θ may be more effective than estimated and recalculate, or recalculate PF using the first equation.

Where:

α = Task Effectiveness (i.e., number of potential failures found divided by total failures (potential and functional)

θ = Probability of detecting a potential failure with the current On Condition task (assuming the potential failure exists)

I = Current Task Interval

Care should be taken in using this method as it is dependent on good in-service data and estimates of θ. The resulting PF should be evaluated using engineering judgment, maintainer/operator input, and any other information sources to ensure it is reasonable and consistent with the failure mode under consideration. The analyst must also consider whether the information from the existing task is indicative of a situation where a consistent PF condition or progression is not a characteristic of the failure mode under consideration, and therefore an OC task would be inappropriate. Once the PF is determined, the methods described in previous paragraphs can be used to set the new inspection interval.

If a different inspection method will be considered for replacing an existing task for a given failure mode, the new inspection interval should be based on the probability of detection of the PF condition (θ) using the new inspection method.

1.3 HARD TIME TASK INTERVAL DETERMINATION

1.3.1 Weibull analysis

Weibull analysis is a statistical technique that uses failure data to provide accurate failure predictions. It provides a method for determining probability of failure as a function of time. This is useful for determining Hard Time task intervals by selecting the time at which the number of occurrences of the failure mode reaches an unacceptable level.

1.3.2 Testing

Testing is another means to determine safe-life limits or wear out ages of items. Many components require certification tests that ensure that the component will operate for a certain period without failure. Aircraft structure, for example, is usually tested to failure under a full-scale fatigue test to ensure that it will remain crack-free for the life of the aircraft. When airframe cracks are found unexpectedly, coupon testing is sometimes performed to determine the life to crack initiation of the suspect component. Statistical techniques such as Weibull may then be applied using the test data to determine appropriate task intervals.

1.3.3 Fatigue analyses

Fatigue analysis can be used to determine an item's life to crack initiation, which, in turn, can be used as a basis to establish a Hard Time task interval. In-service failures that occur because of fatigue may be avoided by setting Hard Time limits at or below the life to crack initiation limit. Appropriate safety factors must be considered and included when establishing these limits.

1.3.4 Determining Hard Time Intervals for Non-Safety Related Failures

Non-safety related Hard Time tasks are only required to cost less than the failure consequences they are designed to prevent. The formula used to ensure this is as follows:

$$CBR = \frac{\dfrac{(C_{BF} \times N_S) + (C_{AF} \times (1 - N_S))}{N_S t + [(1 - N_S) MTTF_P]}}{\dfrac{C_{AF}}{MTBF}}$$

Where: CBR = cost benefit ratio

C_{BF} = cost of rework/replacement before failure

N_S = the percent of items that survive to the proposed task interval

t = the proposed task interval

C_{AF} = cost of repair/replacement and collateral damage (if any) after failure (if operational impacts have been converted to costs, ensure they are included)

MTBF = mean time between failure (with no preventive task in place)

$MTTF_P$ = mean time to failure of items that fail before the proposed task interval

Tasks that have CBR values of less than 1 are considered cost effective. Since $MTTF_P$ may be difficult to obtain, a reasonable estimate may be made using the estimated percentage of the proposed replacement age premature failures will achieve (on average) (i.e., replace $MTTF_P$ with (K x t)). K is the "Premature Failure Factor", or "K Factor". It is defined as the average age of premature failures as a percentage of the task interval. For example, an item with a Hard Time task interval of 1000 FH has had failures that occur on average at 800 FH. Thus, K would be 0.8. If premature failures are expected to be evenly distributed throughout the period before replacement, 0.5 would be a reasonable estimate for K. Items with infant mortality issues will generally have a lower K Factor (and consequently lower $MTTF_P$). If the K Factor is unknown, use a default of 1.0.

Another term that can be illustrated is N_S, the percent of items that survive to the proposed task interval. Consider the same item with the Hard Time task interval of 1000 FH. Out of a population of 100, there have been 25 failures prior to the task interval. 75 items survive to the interval, so N_S would be 0.75 in the calculation.

1.4 FAILURE FINDING TASK INTERVAL DETERMINATION

The probability of multiple failure can be set to a level that is acceptable to a program following the same logic as that used in establishing the acceptable probability of functional failures for evaluating On Condition tasks for hidden safety/environmental failure modes.

The following equation can be used to model the probability of multiple failure condition:

Equation (1) $$P_{mf} = P_{hidden} \times P_{additional}$$

Where:

P_{mf} = Probability of multiple failure occurring
P_{hidden} = Probability of the hidden failure occurring
$P_{additional}$ = Probability of an additional failure occurring

Assuming a random failure distribution for P_{hidden} and $P_{additional}$, equation (2) can be used to model these probabilities of failure from equation (1) by establishing the probability over time:

Equation (2) $$P = 1 - e^{-t / MTBF}$$

Where:

P = Probability over the time period
t = Time period
MTBF = Mean Time Between Failures

The desired MTBF for the function (i.e., multiple failure) can be established by setting an acceptable probability of failure over a known timeframe (e.g., life of the item) and solving for MTBF. If the MTBF for the hidden and additional failure (or event) can be determined (or estimated), the equation is easily solved by iterating the two equations on a spreadsheet to find the appropriate time period (t), which becomes the inspection interval.