S9081-AB-GIB-010

REVISION 1

Reliability-Centered Maintenance (RCM) Handbook

This manual supersedes S9081-AB-GIB-010, dated October 1983, which shall be destroyed.

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Reliability Centered Maintenance (RCM) Handbook

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PURPOSE

This handbook introduces the reader to Reliability Centered Maintenance (RCM) and serves as a supplement to the NAVSEA RCM Level I and Level II training courses. NAVSEA is pleased to provide this handbook as a tool for understanding and implementing RCM. Since the first handbook was released in 1979 a lot has happened. Most significantly RCM at NAVSEA has evolved from a maintenance philosophy to the required methodology for developing and modifying maintenance requirements across all platforms in accordance with Echelon 1 authority.

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Section 1—Introduction to RCM

1.1 Purpose

This handbook provides Navy maintenance practitioners a reference document for applying the principles of Reliability-Centered Maintenance (RCM) to the evaluation of both new and well-established ship planned maintenance system (PMS) preventive maintenance requirements. It is intended as a supplement to the Naval Sea Systems Command Reliability-Centered Maintenance-based certification program for those who develop, modify, review and authorize Planned Maintenance System tasks for Navy ships, systems, and equipment. The handbook introduces basic principles of maintenance and illustrates how these principles establish rules for good maintenance tasks. It describes how these rules are used to develop maintenance requirements and associated documentation for new systems and equipment as well as to evaluate and improve the quality and effectiveness of well-established maintenance programs.

Requirements for analysis of preventive maintenance requirements and for development of associated support documentation are defined in MIL-P-24534A, "Planned Maintenance System: development of Maintenance Requirement Cards, Maintenance Index Pages, and Associated Documentation."

1.2 History of RCM

Logical methods for designing preventive maintenance programs started about a half century ago. This brief history sets the stage for detailed discussion of the Reliability-Centered Maintenance methodology mandated by the Chief of Naval Operations for ship maintenance. OPNAVINST 4700.7(series) "Maintenance Policy for U.S. Navy Ships," and OPNAVINST 4790.4(series) Ships' Maintenance and Material Management (3-M) System Policy require the use of RCM for the development of maintenance programs and associated maintenance tasks.

Efforts to look deeply into the effectiveness of preventive maintenance as a process for avoiding failure began in the late 1950s. Those involved in establishing preventive maintenance requirements before then may have been so convinced of the value of their actions that they saw no need to prove its truth. They reacted almost entirely to each event as it occurred rather than to generalize their experience.

The introduction of jet aircraft fleets led the airline industry to apply a growing expertise in the process of analysis to improving the effectiveness of preventive maintenance for transport aircraft. Since the underlying reason for preventive maintenance is the belief that reliability of hardware decreases with use, the first efforts examined the relationship between reliability and age (use). This was done by application of techniques already used by life insurance actuaries.

In 1967, the airline industry's Maintenance Steering Group (MSG) first applied decision tree logic – a series of questions that lead to a supportable maintenance task decision – to the problem of identifying required preventive maintenance tasks. This predecessor of RCM proved an efficient approach, since it focused directly on the impact of unreliability on operations and safety. The following year, decision tree logic formed the basis for design of the initial Boeing 747 maintenance program. In the ensuing years, the airline industry updated the MSG approach and applied it to such aircraft as the Boeing 767 and beyond.

In the early 1970s, this work attracted the attention of the Office of the Secretary of Defense, the Naval Air Systems Command, the Air Force, and the Army. The Navy was the first to apply this new philosophy and an improved methodology called Reliability-Centered Maintenance (RCM) to both new design and in-service aircraft.

In 1978, United Airlines published a book prepared under contract to the Office of Assistant Secretary of Defense (Manpower, Reserve Affairs and Logistics) detailing the RCM methodology. This book, *Reliability-Centered Maintenance* by Stanley Nowlan and Howard Heap and the work leading to its publication formed the basis for the Naval Sea Systems Command application of RCM to ship maintenance.

The prototype application of RCM to surface ship preventive maintenance was installed in USS ROARK (FF-1053) in 1978. Following evaluation of results on four additional FF-1052 class ships, the Chief of Naval Operations directed that RCM be used for development of scheduled maintenance tasks for all new and in-service naval ships in accordance with MIL-P-24534A, *Planned Maintenance System*. This application is now called "Classic RCM."

The principles of RCM were also applied to ship depot level maintenance in the Phased Maintenance Program (PMP) developed initially for Combat Support Ships in the early 1980s. This program, which was later expanded to all auxiliary ships, amphibious ships and certain combatant ships, served as the catalyst for Continuous Maintenance (CM). CM is a nearly continuous process of identifying, screening, authorizing, planning, and accomplishing maintenance at all maintenance levels (organizational, intermediate, and depot). The underlying policy for both PMP and CM is called Condition-Based Maintenance (CBM), which is the CNO's policy for ship maintenance as called out in OPNAVINST 4700.7(series). CBM is defined as maintenance based on objective evidence of need. OPNAVINST 4790.16, "Condition-Based Maintenance Policy," requires use of RCM to determine evidence needed to select appropriate maintenance.

Benefits derived from the use of RCM to establish maintenance programs eroded over the years because the Navy tended to overlook an important part of the RCM process – periodic analysis of operational and maintenance feedback to continuously improve the periodicity and scope of prescribed maintenance tasks. This became critical in the 1990s, when construction of new ships fell prey to the cost of maintaining in-service ships.

Recognizing that adopting change based on operating experience is a major component and benefit of RCM, the Naval Sea Systems Command developed an RCM methodology to be used to improve existing preventive maintenance programs in 1996. A prototype of the so-called RCM 'Backfit' Methodology was applied to the USS YORKTOWN (CG-48) Planned Maintenance System (PMS) as part of the Smart Ship Program. Results included a 46.7 percent reduction in ship's force PMS workload without adverse impact on safety, mission, or the environment. This approach has been refined and is applied to all shipboard systems by Navy In-Service Engineers (ISEs) in conjunction with ship's force personnel experienced in operation and maintenance of the systems evaluated. Both the ISEs and involved ship's force personnel are provided training in Backfit RCM prior to conducting their analyses of existing PMS tasks during an evaluation called Ship Maintenance Effectiveness Review (SHIPMER).

This handbook addresses both the 'Classic' RCM approach for development of new maintenance requirements for systems and equipment and the RCM 'Backfit' approach for validation of maintenance requirements for in-service systems and equipment.

1.3 Basis for RCM

RCM is derived from careful consideration of basic questions such as the following:

- What functions does the system perform?
- What functional failures might occur?
- Which of the functional failures are likely to occur?
- Are the functional failures evident to the operating crew?
- What are the consequences of failure on safety, mission, and cost?
- What is the relative risk of failure in terms of probability of failure and severity of failure?
- What, if anything, can be done to prevent likely failures?
- What is the cost of trying to prevent failures?

RCM is reliability-centered. Its objective is to maintain the inherent reliability of the system or equipment design, recognizing that changes in inherent reliability may be achieved only through design changes. Within this constraint, RCM functions to determine what preventive maintenance is required to:

- Ensure safety of personnel, protect the environment and equipment; and
- Provide reasonable assurance of being able to accomplish the ship's mission at a cost less than that of correcting the failure the preventive task is trying to prevent.

Classic RCM develops maintenance tasks for new systems by:

- Partitioning the ship into systems and subsystems that require analysis;
- Identifying functionally significant items;
- Determining any needed maintenance requirements (tasks) for each significant item based on analysis of its functions (both evident and hidden), its dominant failure modes, and management of risk associated with functional failure;
- Determining when, how, and by whom each task should be accomplished; and
- Identifying any need for design change:

    – When safety is threatened by a failure for which there is no applicable and effective preventive task, or
    – When inherent reliability proves to be less than adequate.

Backfit RCM validates existing maintenance tasks by using information from operations and maintenance in a streamlined analysis, and adjusting task intervals and task content where appropriate.

The identification and application of fundamental maintenance concepts (e.g., risk management) provides the maintenance practitioner a foundation for future application.

1.4 RCM Certification

The Chief of Naval Operations (CNO) has mandated that Condition-Based Maintenance (CBM) practices be implemented in all Navy maintenance decisions involving ships, aircraft, and infrastructure in OPNAVINST 4790.16. The instruction tasks NAVSEA to "provide procedures and training for the implementation of CBM…." The objective of condition based maintenance is that maintenance is performed based on objective evidence of the need. Reliability Centered Maintenance (RCM) is the process that is used to develop the maintenance tasks needed to implement CBM. To achieve the CNO's CBM goal, NAVSEA 04RM established the RCM Certification Program. The Naval Sea Systems Command certifies all those who develop, review, or approve scheduled maintenance requirements to ensure that RCM principles and approved methodology are properly employed in maintenance plan development for Organizational, Intermediate, and Depot (OI&D) levels. RCM certification is required for all PMS practitioners in accordance with Appendix J of NAVSEAINST 4790.8(series), Ship's Maintenance and Material Management (3-M) Manual. NAVSEA 04RM manages the RCM Certification Program and associated training.

Each equipment system placed in a U.S. Navy ship has an experienced shore-based In-Service Engineer (ISE) responsible for monitoring lifecycle as well as individual problems in that system. The RCM Certification Program affects all individuals who either develop new PMS, or make changes to existing PMS. Those persons, whether they are Navy employees or contractors must achieve and maintain the appropriate level of RCM certification relevant to the work they are performing.

ISEs are challenged daily with design and maintenance issues. NAVSEA's RCM Certification Program ensures that they are equipped with the skills required to develop, review or approve changes to PMS. RCM Certification comprises three certification levels.

Level I - Backfit RCM for Practitioners: Level I certification is required for ISEs, Commodity Specialists or contractors who modify existing Planned Maintenance System (PMS) maintenance tasks. The course is two days in duration and taught by an approved SEA 04RM instructor. This course provides training in the fundamental CBM topics and methodologies to be employed when performing an engineering review of existing PMS maintenance tasks. Upon completing certification, individuals apply this methodology to every maintenance related assessment they perform. Level I certification is valid for three years and can be renewed by attending another Level I training class, a Ship Maintenance Effectiveness Review (SHIPMER) session, or by satisfactorily completing an online recertification examination.

Level II – Classic RCM for PMS Requirement Developers: Level II certification applies to ISEs, Commodity Specialists or contractors who develop or approve maintenance requirements for new systems or equipment. The course begins with an introduction to maintenance engineering and RCM fundamentals and leads to detailed instruction in the MIL-P-24534A (Navy) process for developing maintenance task requirements for Navy equipment. The student is guided through multiple practical application examples to further illustrate the RCM process and to prepare for the certification examination. The course is five days in duration and taught by an approved NAVSEA 04RM instructor. Level II certification is valid for three years and can be renewed by attending another Level II training class or by satisfactorily completing an online recertification examination.

Level III – Navy Backfit RCM Trainer: Level III certification applies to a very small number of ISEs who have been selected to teach the Level I certification course within their command or activity. Individuals selected for Level III training must be certified in both Level I and Level II and demonstrate a high level of proficiency in RCM as outlined in MIL-P-24534A (Navy). The Level III course is composed of two major elements and is two weeks in duration. The first week is devoted to an intensive review of RCM theory and application including a comprehensive examination of RCM fundamentals and instructor oriented training in the RCM Level I curriculum. The second week is an introductory course on adult training techniques and includes opportunity to practice the presentation of the RCM Level I course material in a controlled environment. Level III certification requires the demonstration of instruction proficiency of the RCM Level I course material and is valid for one year. Renewal of certification is contingent upon successful demonstration of continued proficiency to NAVSEA 04RM or designated technical warrant holder.

1.5 Summary

In 1967 the airline industry's Maintenance Steering Group (MSG) applied the first decision logic tree for development of preventive maintenance. This work grew out of a comprehensive review of maintenance practices begun in the late 1950s. By the 1970s, a systematic approach for the development of maintenance had become known as "Reliability-Centered Maintenance" (RCM). The fundamental goals of RCM were to maintain system functionality by ensuring all maintenance actions were designed to maximize system reliability at minimum cost. To accomplish this, the RCM process is a structured approach that requires the analyst to justify maintenance requirements by answering a series of questions.

- What functions does the system perform?
- What functional failures might occur?
- Which of the functional failures are likely to occur?
- Are the functional failures evident to the operating crew?
- What are the consequences of failure on safety, mission, and cost?
- What is the relative risk of failure in terms of probability of failure and severity of failure?
- What, if anything, can be done to prevent likely failures?
- What is the cost of trying to prevent failures?

The US Navy began applying RCM to surface ship maintenance in 1978. Within a few decades RCM has become a fundamental part of the Navy's Conditioned Based Maintenance (CBM) Policy. To ensure RCM principles are understood and applied across all maintenance decisions during a ship's entire life cycle, Naval Sea Systems Command has instituted a certification program. All personnel associated with the development, review, or approval of scheduled maintenance requirements are required to undergo training in RCM fundamentals as they apply to existing maintenance (Level I) or new maintenance (Level II).

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Section 2—Fundamentals of Maintenance Engineering (ME)

This section briefly explains nine fundamental maintenance concepts that govern the development, implementation, execution, and continuous improvement of ship maintenance programs. These are core principles of RCM. These nine fundamental concepts are:

- Failures happen.
- Not all failures have the same probability
- Not all failures have the same consequences
- Simple components wear out, complex systems break down
- Good maintenance provides required functionality for lowest practicable cost
- Maintenance can only achieve inherent design reliability
- Hidden functions require special treatment
- Unnecessary maintenance takes resources away from necessary maintenance
- Good maintenance programs undergo continuous improvement.

These concepts form a progression of maintenance engineering thought from the most fundamental concept — failures happen — to the greatest challenge for any maintenance program: establishment of a process for continuous improvement.

2.1 Failures Happen

It is appropriate to begin discussion with the fact that functional failures -- unsatisfactory conditions in which intended functions are not adequately provided -- happen.

Maintenance planners know intuitively, if not by personal experience, that unexpected failures happen. Nevertheless, they tend to approach the business of maintenance program planning from one of two very different directions. One direction is to attempt to eliminate all failures. The second direction is risk management. There are many factors in equipment reliability that can cause a failure. They include stress, corrosion and fatigue. A maintenance program can be used to prevent or preclude such failures. However, there are failures caused by things beyond the control of the maintainer. These include unplanned or random events (sudden high-energy impact, lightning strike, etc.), sometimes called acts of God. There is nothing that can be done to prevent these failures, especially from an economic standpoint. There are failures caused by poor manufacturing quality. These types of failures cannot be prevented by maintenance.

We know that not all failures can be prevented. Good maintenance programs don't try to prevent all failures; they couldn't if they tried! Good maintenance programs will minimize the number of failures, however, perhaps even to the point where they appear to have been totally eliminated.
The paradigm of attempting to prevent **all** failures has lead to extremely costly maintenance programs that do not succeed because all failures cannot be prevented. The important thing is to focus resources on failures that **can** be prevented.

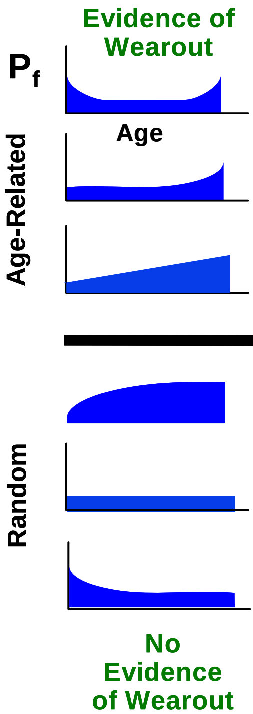
2.2 Not All Failures Have the Same Probability

Reliability engineers define reliability as the *probability* that equipment will provide its desired function over a specified period of time. When maintainers speak of probability of failure, they really mean the rate at which a piece of equipment will fail over a period of time, i.e. the frequency, or rate, of failure. Things to consider about probability of failure are: Is that probability, or rate, of failure a function of time? Is it increasing in frequency? (a bad thing), Is it decreasing in frequency? (a good thing), or is it constant. A constant failure rate is often called random *failures*. It is often said that complex equipment experiences random failures. So how do real-world equipment failure rates compare to our preconceived notions about probability of failure?

The pioneering work on Reliability-Centered Maintenance performed by United Airlines began with a study of hardware age-reliability characteristics. When United disassembled engines for repair, it found some engines whose internal components were in good condition and some engines whose internal components were in poor condition. Further, when United began to explore the age-reliability relationship by introducing these engines back into service after minimal repair, it found that some engines with internal components in good condition exhibited lower reliability in service than engines with components in worn condition. United realized that it did not have as firm a grip on the relationship between time in service (or “age”) and reliability as it thought. Reliability degradation is a reduction of an item’s resistance to failure.

United Airlines applied the same technique used by insurance actuaries when developing mortality curves for human beings. This technique was used to explore the relationship between the failure-rate or *conditional probability of failure* and some measure of operating age for aircraft hardware. The conditional probability of failure is the failure rate of the component with respect to time. A constant conditional probability of failure means that the failure rate is not increasing or decreasing with respect to time, it means that we have random failures.

The results of United’s initial exploration of this relationship are shown in Figure 2.1 in column marked UAL, which were developed from a study of 139 aircraft components and equipment. These results show both wear out (age-related failures, curves A, B, and C) and random failures (curves D, E, and F). The figure also includes similar results from later studies.



	UAL	Broberg 1973	MSDP Studies 1983	SSMD 1993
A.	4%	3%	3%	6%
B.	2%	1%	17%	
C.	5%	4%	3%	
D.	7%	11%	6%	
E.	14%	15%	42%	60%
F.	68%	66%	29%	33%
No Evidence of Wearout	89%	92%	77%	93%

(Figure 2.1.) Age-Reliability Characteristics Curves.

Analysis showed that:

1. Random failures predominate compared to age-related failures. Infant mortality (i.e., high initial probability of failure, decreasing with age) is common.
2. Infant mortality persists (significant time is required to transition out of infant mortality to steady state conditional probability of failure).
3. The conditional probability of failure is never zero.
4. The shape of the age-reliability characteristic curve is highly configuration-dependent.
5. Simple items tend to exhibit wear out (curves A, B and C) whereas complex items tend to exhibit random failures (curves D, E and F).

Curves D, E, and F should not be interpreted to mean that some items never degrade or wear out. These curves simply show the life of some items came to an end before wear out was evident, perhaps because they were removed for restoration, or were replaced with modified or upgraded items. Everything will eventually degrade with time, but some items degrade so slowly that wear out is not a concern since the degradation will not adversely affect performance during the life of the ship. Degradation of the glass in the bridge windows, for example, does not trouble the maintenance planner, who needs to focus on items whose degradation is of real concern.

Age-reliability characteristics curves can tell a maintenance planner whether or not wear out (increase in the conditional probability of failure) exists. If there is no evidence of wear out, there is no good basis for a time-directed life-renewal task. It makes no sense to spend maintenance resources to renew the life of an item whose reliability has not degraded or which may have actually improved with age.

It is not necessary to develop age-reliability characteristics curves for every item of equipment. In fact, these curves should be limited to a small set of high-value items where the investment cost of curve development will be returned in reduced life-cycle maintenance requirements. Maintenance planners need to keep these curves — and the lessons they teach — in mind as they review maintenance for the items for which they are responsible.

Rapid increase in the conditional probability of failure of an item may be associated with a component, subassembly, or assembly within an item — or it may be typical of the complete item. The more complex an item, the less likely it is that all its constituent elements will have the same age-to-failure characteristics.

2.3 Not All Failures have the Same Consequences

Maintenance is an investment, an indirect cost that organizations are willing to bear with the expectation they will receive a benefit in the form of sustained personnel safety and system reliability that exceeds the magnitude of their investment. The *consequence* of failure of an item is a very important consideration when considering appropriate levels of maintenance. In RCM we refer to the consequence as *severity of failure*.

We saw in Section 2.2 that the conditional probability of failure is never zero. Because there is always a chance of a component or a system failing, the *severity* of that failure is very important. It is also important not merely to focus on what happens to a component when it fails, but what happens at higher levels. Severity should be considered at the highest level, i.e. what happens to the ship when the component fails? A good example is a bearing in a ship's fire pump. If the bearing fails, we know that we will need a replacement. An immediate reaction would be to consider this a critical failure, but we must look at the overall effects. How many fire pumps are onboard and how many are required for system pressure? i.e. How much redundancy is there? Is there a cross connect from the seawater service system? It is important for the analyst to consider the overall effect to the ship, to see the big picture.

The consequence of any failure may be categorized as impacting Personnel, Safety, Ship Mission and All Others. Obviously, the highest level of severity is a Sailor being injured or killed; this is a Safety related failure. The next level down in importance is the Mission level. Will the failure affect the mission of the ship? If the failure does not affect safety or mission, than it falls into the "all others" category and preventing the failure is primarily an economic decision; the cost of doing the preventive maintenance must be less than the cost of correcting the failure that the maintenance is trying to prevent. It is important to recognize that not every failure results in death or injury; not every failure will impact the ship's ability to perform its mission. As a result, we must always make a *realistic* assessment of each failure's consequences. The probability and the severity of a failure factor into the concept of *risk*.

Everyone involved with maintenance should understand the fundamental concepts of risk in order to deal with it objectively and effectively. Maintenance practitioners need to know what risk is, how it can be assessed, and how it can be managed as part of a sound maintenance program.

Most people asked to define "risk" identify it as a threat, a hazard, or a very undesirable situation. They clearly associate "risk" with adverse circumstances. This may be correct, but it presents only one aspect of risk.

Risk is composed of two factors: the probability of failure (P_f) of an item and the severity of failure consequences (S_f). Thus, from a mathematical perspective:

$$\textbf{Risk} \equiv \mathbf{P_f} \times \mathbf{S_f}$$

This definition of risk is very important. The natural tendency is to focus on the severity of failure, but not all potentially adverse failures are likely to occur.

The probability of a failure is at least as important a consideration in the objective assessment of its risk as is failure severity. The design of a well-balanced and effective maintenance program requires that both these factors be considered. Neglecting S_f could result in overlooking needed coverage for a failure mode that could injure or kill a member of the operating crew, damage the environment, or cause loss of a critical mission capability. Neglecting P_f could result in the unnecessary expenditure of resources to "prevent" a failure that may never occur.

A well-designed maintenance program uses the concept of risk to allocate resources where they will provide the greatest benefit. It assesses the risk of failure that confronts individual ship systems and equipment, and it allocates resources to prevent failure on the basis of that risk assessment. It recognizes the "opportunity cost" of each maintenance decision: unnecessary maintenance that reduces resources available to accomplish needed work in other areas that must then be deferred for lack of resources.

Now that we know what "risk" is, we need some way to evaluate or assess it. We can begin by looking at dominant failures modes.

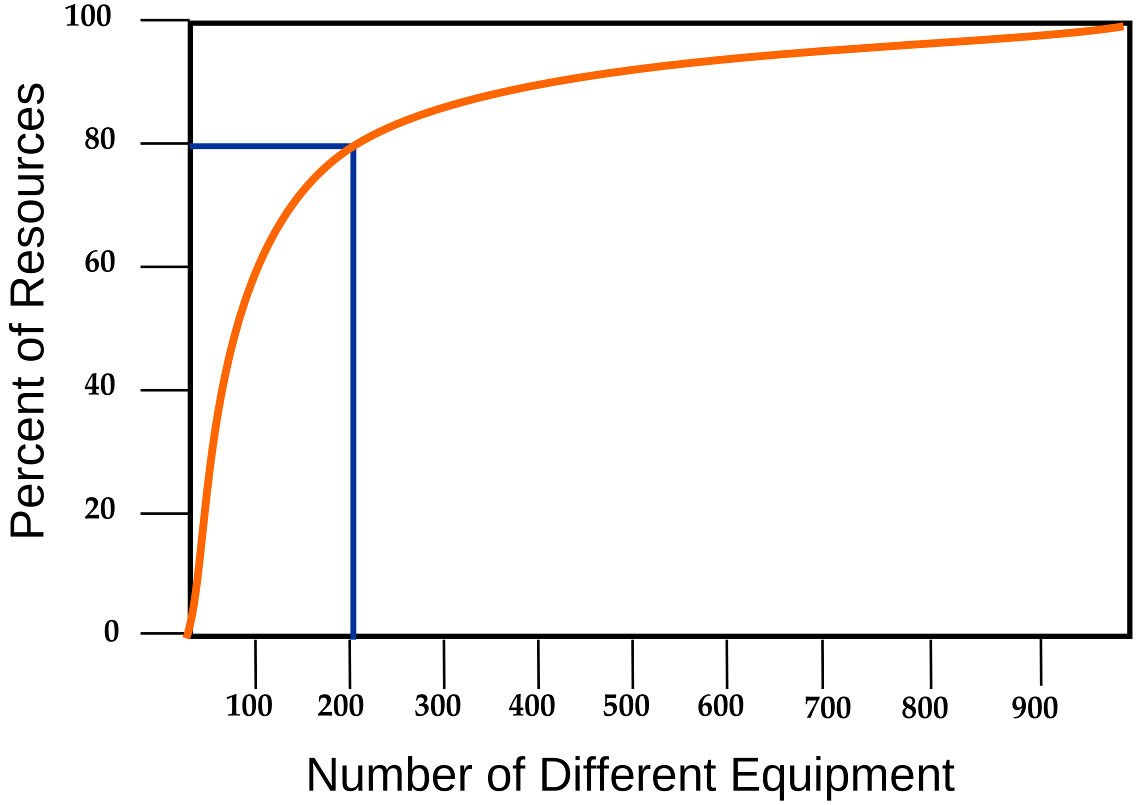
Dominant failure modes occur frequently or have serious consequences

There are two specific considerations used to identify dominant failure modes:

- First, the failure mode should appear relatively often in material condition analyses. It should constitute a relatively large proportion of the total number of failures, or it should appear in significantly degraded condition in a large proportion of diagnostic tests or inspections. The sample size must be adequate to establish confidence in the results.

- Second, a failure that does actually occur should be considered dominant if it has serious consequences, regardless of frequency of occurrence. Serious consequences could be such things as personnel injury or death, loss of mission capability, or expensive repairs.

A 19th century Italian economist named Pareto once stated that 20 percent of Italy's population controlled 80% of the nation's wealth. This became known as the Pareto Principle, and has many applications, including maintenance. As shown in Figure 2.2, dominant failure modes account for the majority of failures. Those dominant failure modes that don't fit the description of frequent occurrence are failures that have such severe consequences that they must be considered for preventive action despite their low probability of occurrence. The curve of Figure 2.2 also applies to the application of maintenance resources. Twenty percent of systems or equipment consumes about 80 percent of maintenance resources.



20% of Failure Modes Cause About 80% of Failures; in addition, 80% of Maintenance Resources Are Applied to About 20% of Equipment.
(Figure 2.2)

Note: This graph displays theoretical data derived from the Pareto Principle.

Failure modes that create personnel safety hazards dominate consideration by the severity of their potential consequences. All failures that involve safety must be considered no matter how remote the probability of failure: no one puts a price on the life or limb of the operating crew.

Failure modes whose effects are severe with respect to such things as mission or expense should also be considered, accounting for severity as a risk factor.

Failure modes that are most likely to occur dominate the population of failures by their frequency of occurrence. This consideration accounts for probability of failure as a risk factor, as it focuses on failure modes of most likely concern. The maintenance analyst doesn't need statistically valid figures for P_f accurate to two or three decimal places to proceed with the analysis. Navy maintenance data collection and analysis systems have not yet reached the point where discrete, widely accepted values for system and equipment P_f are available. Fortunately, broad or general values for P_f can and should be used until more detailed figures are developed. Even the use of such broad values of P_f permits comparing the relative risk of different work items where tradeoff decisions involving funding must be made.

Next, we consider the second element of risk assessment: severity of failure.

The Classic RCM analysis process evaluates the severity of failure at three different levels.

The first step is the component level, which is an evaluation of failure severity at the local (or equipment) level. The principal concern at this point is whether the failure mode will cause injury or death to operating personnel in the vicinity at the time of failure. A secondary concern at the local level is whether the failure will cause complete loss of the equipment, i.e., require rebuild or replacement of the equipment or simply replacement of a component. The answer has implications for material procurement and corrective effort.

The next step, the subsystem/system level, is to examine severity of failure within the system boundaries. The concern here is loss of system functionality, including safety issues related to loss of function. Some systems have redundant subsystems; loss of one subsystem has no immediate system impact, thereby reducing the severity of failure. The steering system is one example of this, as it has both port and starboard subsystems. Loss of one side is compensated for by operation of the other.

The final step examines severity of failure outside the bounds of the system. The concern here is loss of mission capability. Ship systems are the basic building blocks of ship mission capabilities; loss of a ship system can mean loss or significant degradation of a mission capability. The effect of failure on ship mission capability can be highly varied. Loss of the electronic countermeasures system may jeopardize the ship in a combat situation, but loss of the potable drinking water system will put the ship out of business in any situation.

So failures have different consequences: safety or regulatory, mission, and economic. The maintenance analyst and the maintenance planner must evaluate these consequences to determine the exact nature of severity of failure as it relates to risk.

Both risk factors, P_f and S_f, are considered in the decision to either conduct a risk management analysis or to eliminate it as a source of concern. If in doubt, the default decision is to carry the functional failure and the failure mode forward for analysis. The entire purpose of risk assessment is to decide whether to eliminate failures of little significance from further preventive maintenance analysis.

We recognize that it simply is not possible to prevent all failures. **Further, it is not even worthwhile to prevent all failures**. It is possible to reduce the number of failures to an acceptable level and then to manage the risk assessment of that small number. That is what good maintenance is all about. Excessive maintenance that attempts to prevent all failures does not fit the definition of "good maintenance."

2.4 Simple Components Wear Out, Complex Systems Break Down

This was mentioned briefly in the previous discussion on age-reliability curves, but we will now discuss this concept in greater detail. A "simple" component is something that has relatively few failure modes. Some examples are the timing belt in an automobile, the roller bearing on a drive shaft, the cable on a crane. Simple items often exhibit some particular sign of distress before they fail (i.e., they provide evidence of potential failure). For example, a radiator hose in your car most often fails by rupturing. A soft or bulged hose is an indication that failure is near. For such failures, a knowledgeable planner can often design a task to detect the evidence of potential failure and take corrective action prior to failure. When we say "wear out," we mean that there is a marked increase in the conditional probability of failure. As can be seen in Figure 2.1, the conditional probability of failure for curves A and B show this. In each case, the conditional probability of failure has a "wear out" age. If the maintenance planner knows the typical wear out age for a component, it is easy to develop a schedule to replace the component before failure.

Complex items tend to breakdown through random failure. Complex items contain many simple components, each having its own failure modes. Because there are so many components in a complex item, no single failure mode tends to dominate. Because complex items have a large variety of failure modes, they typically do not exhibit a wear out age. Their failures do not tend to be a function of age. Failures of complex systems most often occur *randomly*. Their conditional probability of failure is generally a constant. These constant conditional probability of failure equipments are represented by curves E and F in Figure 2.1.

These differences between simple and complex components are important with respect to maintenance strategies. *Because we do not have a wear out age for complex items, the practice of performing time-driven overhauls on such items is wasteful of resources.* One spends money fixing things that do not need to be fixed! Only when we can show that an item exhibits a wear out age does performing an overhaul or replacement of that component at a particular time or age make sense.

2.5 Good maintenance provides required functionality for lowest practicable cost

We previously defined maintenance as action to ensure that items provide their intended functions when required. Good maintenance, therefore, serves to maintain or restore function.

Our definition of maintenance is helpful but does not help the analyst or manager to differentiate good maintenance from other maintenance. To do that, the analyst needs to evaluate the cost of performing preventive maintenance against the cost and other consequences of not performing the maintenance. A good maintenance program delivers required system, subsystem, and equipment functions for least cost, i.e., least total expenditure of resources.

The statement that "good" maintenance delivers "required" functionality means that it delivers functions essential for satisfactory operation when they are needed. Good maintenance satisfies actual, but not necessarily theoretical, demands.

The essential nature of good maintenance is to ensure that the hardware does what is required of it when required, not that it be wholly capable of achieving its full design capability at all times.

Hardware may be capable of doing much more than what is required of it. *Maintenance efforts to ensure that hardware produces greater capability than needed are a waste of resources.* We do not maintain our automobiles so they are capable of running at their maximum rated speed every day; we maintain them so they will deliver normal driving speeds. Cost effective maintenance serves to preserve the functions required by the user.

2.6 Maintenance Can Only Achieve Inherent Design Reliability

A very important point to consider about maintenance and design capability is that maintenance can only restore or preserve the hardware's inherent design reliability and performance characteristics. If the design's inherent reliability or performance is poor, doing more maintenance will not help. To improve poor reliability or performance attributable to inadequate design, one must change the design.

Systems and equipment do not always have to "look like the blueprint" or meet design specifications to deliver required functionality. There is no need to invest maintenance resources to attain greater performance than needed. The design engineer typically incorporates various margins in the design specifications. These margins provide protection from such conditions as corrosion and erosion in the operating environment and abnormal levels of stress from performance outside prescribed operating ranges. They also take into account dimensional variations from manufacturing processes, differences in the material composition of constituent parts that comprise the complete item, and other factors. In addition, functional performance parameters, such as pump pressure and throughput, required by procurement specifications or available in commercial off the shelf (COTS) equipment may be greater than required for adequate system performance. The shipbuilder may select an available 250 gpm pump, for example, rather than procure a new pump design to provide 225 gpm required by design specifications.

2.7 Hidden Functions Require Special Treatment

We must now ask the question, what is a hidden function, and why does it require special treatment? Some organizations perform mostly corrective maintenance, i.e. fix-when-fail, opting not to take equipment offline to perform preventive maintenance. But what happens when you have a failure that is not visible or evident to the operating crew? For example, an emergency device like a fire sprinkler system, alarm system, or an overspeed shutdown device may have failed. How will you know whether those devices have failed until such time as their function is required?

The answer is that you will not know about a hidden functional failure until it is too late, unless you perform a procedure to test for that hidden failure.

A maintenance task to find a hidden failure, a failure finding task, does not actually prevent that failure. It seeks to find a failure that has already happened that you do not know about. The rest is troubleshooting and corrective maintenance. The goal is to find that failure before it becomes a larger problem. For example, you don't want to find out your smoke detector has failed by discovering you have an out of control fire in your home. You don't want to find out that your boiler safety relief valve has failed by the fact that your boiler has just ruptured. You do the failure finding test to help ensure the availability of those protective or safety devices when they are needed.

What failure finding tasks do prevent are multiple or cascading failures. Cascading failures have a very small probability of occurring because they depend upon several events, each with its own probability happening at the same time. For example, even though they have a small probability of failure, some cascading failures are worth trying to prevent because their consequences are so severe. Most people will agree it is good to inspect for hidden failures that involve safety or mission consequences. However, it must be understood that the very act of testing some safety or protective devices causes undue wear on them and may result in premature failure. For maintenance associated with hidden failures, it is important to consider not only the consequence of failure, but the consequence of over-testing.

2.8 Unnecessary maintenance takes resources away from necessary maintenance

There is almost always more maintenance to do than resources to do it with. If one wastes resources doing unnecessary maintenance, there won't be enough available to perform the truly necessary maintenance. Inadequate investment in maintenance has adverse consequences. It is not difficult to understand that deferring or eliminating valid maintenance will increase an item's probability of failure. On the other hand, excessive investment in maintenance also has adverse consequences. There are several ways this takes place.

First, many maintenance actions require systems or equipment to be off-line when maintenance is performed. Every minute an item is off-line for maintenance is a minute not available for operations. This time off-line penalizes the ship with decreased operational availability (A_o).

Second, some maintenance actions induce "infant mortality" [i.e., increased conditional probability of failure after maintenance] as a result of such factors as human error, the use of defective material, or errors in technical documentation. If the maintenance were *not* mandated, there would not be the exposure to infant mortality and no penalty in decreased operational availability would result.

Third, excessive maintenance requirements may result in maintenance accomplishment that is less thorough than required because maintainers don't have the time necessary to accomplish all tasks properly. This can also occur when maintenance personnel don't believe in the value of the tasks they are performing and perform tasks in a superficial manner. The odds of performing maintenance properly increase when maintainers are convinced of its intrinsic value.

Fourth, an adverse mismatch between maintenance task workload and maintenance manpower available may present the work center supervisor aboard ship a difficult choice:

- Perform every task as best as possible with the manpower available, taking shortcuts where necessary but "accomplishing" every task;
- Perform some tasks thoroughly with no shortcuts and defer the remainder; or
- Some combination of the two.

Thus, too much maintenance is not necessarily a better situation than not enough maintenance. The most desirable maintenance program matches the investment of resources to the priority of requirements as closely as possible. This approach provides the most effective use of maintenance resources to achieve necessary operational availability for any level of maintenance resource allocation.

2.9 Good Maintenance Programs undergo Continuous Improvement

The most effective maintenance programs are dynamic: they are changing and improving regularly to make ever better use of resources the longer they are in operation. They regularly test and explore the boundaries of maintenance, obtaining increasing knowledge of the items being maintained as they proceed, while accepting unexpected failures as the price of progress.

The Navy in peacetime should be a laboratory for the Navy at war. The Navy in peacetime should learn all it can about system and equipment failure and the effectiveness of maintenance tasks so that these lessons are available for use in war. Operational commanders need the greatest possible flexibility for decisions in war to have the greatest opportunity for success in combat. This includes maintenance.

Many different types of changes can be recommended to effect improvement, but improvement should not stop with the first change recommendation. Well-designed and well-managed maintenance programs continue to push the limits of tasks that already meet the basic criteria for applicability and effectiveness.

Extending the periodicity of an oil change from 3,000 miles to 6,000 miles can save money. Such action increases the value of a task by reducing its cost without affecting reliability. But what if the oil will actually provide satisfactory service for 7,500 or 10,000 miles? Ending the exploration of the limits of lubricating oil quality at 6,000 miles would miss the greater benefit that could have been gained from further exploration.

The highly effective maintenance manager will keep two maintenance improvement considerations in mind. The first consideration is a short priority list of initiatives that may be used to improve maintenance task effectiveness. The second is a hierarchy of different data analysis efforts that may be used to focus the priority of data collection efforts.

Not all improvement initiatives have the same potential payoff leverage. The wise maintenance manager will seek out opportunities to obtain the greatest leverage. Similarly, not all data have the same value. The wise maintenance manager will structure data collection, analysis, and display capabilities to give the most necessary information for continuing to make improvement while operating safely and reliably.

Priorities for different maintenance improvement initiatives

Not all maintenance improvement initiatives have the same leverage.

Eliminating unnecessary maintenance tasks has the highest potential leverage. This action eliminates maintenance labor, direct and indirect material, and the administrative burden of scheduling, managing, and reporting on maintenance accomplishment.

The next highest potential leverage initiative is action to change time-directed life-renewal tasks into condition-directed tasks.

Another improvement initiative involves analytical or empirical <u>age exploration</u>: extending task periodicity based on data analysis results, operator and maintainer experience, or good engineering judgment and then observing the results. The shorter the current periodicity, the greater the leverage is from a recommendation to extend periodicity. Adjusting a daily periodicity to a weekly periodicity reduces required PMS workload for that task by more than 80%. This is not the only way to improve a task, but it may be the simplest and often the most effective improvement to make.

A variety of other alternatives follows: reducing the scope of a task, using a sampling process to estimate condition in lieu of conducting 100% inspection, changing calendar-based task scheduling to situational scheduling, and so forth.

When the maintenance manager understands the differences in improvement leverage provided with different alternatives, he or she can focus on approaches that can provide the greatest potential payback for an investment in change management.

Maintenance data requirements

Just as various failures do not have the same consequences, not all data have the same value. The highly effective maintenance manager will organize data collection and analysis to identify and take advantage of data with the greatest value.

Data with the greatest value to the maintenance manager are those related to critical events: failures or condition measurements that relate to events that affect personnel safety, protection of the environment, or ship mission capability. Some data are critical:

- Critical data must not be overlooked or otherwise missed because critical safety or mission capability requirements are involved;
- Critical data must be displayed to decision makers quickly (i.e., as soon as practicable after they are "captured" or processed); and
- Critical data must be recorded accurately and comprehensively, in a machinery history or similar database for future reference.

It is no trivial exercise to identify these data. Unless they are carefully identified, however, and provisions made for their comprehensive and accurate capture, analysis, and display, the maintenance manager will be inclined to make decisions based on folklore and mythology as well as facts. Therefore, the requirements must be identified first and then the system to support them can be designed and implemented.

Data needed to develop specific failure rates have the next greatest value. The maintenance manager may not be interested in the failure rate of the food mixer but will certainly be interested in the failure rate of sensors, main propulsion items, or primary weapons systems components, for example. Condition measurement data can be used to develop material condition trends, and be used to help predict and improve failure rates.

Finally, some data may be needed to develop age-reliability characteristics curves to evaluate the effectiveness of selected maintenance actions, principally life-renewal tasks. The development of these curves is time-consuming and expensive; they should only be developed where reasonable expectation exists that they will reduce maintenance costs to an extent that more than offsets the cost of their development.

Regardless of the merit of specific improvement actions taken by individual maintenance managers, the message for all maintenance managers is to ensure continuous maintenance improvement. The ongoing process of developing, implementing, and following up on the results of an improvement program is essential for well-run maintenance.

2.10 Summary

A thorough understanding of the nine fundamental concepts of maintenance engineering…

- Failures happen
- Not all failures have the same probability
- Not all failures have the same consequences
- Simple components wear out, complex systems break down
- Good maintenance provides required functionality for lowest practicable cost
- Maintenance can only achieve inherent design reliability
- Hidden functions require special treatment
- Unnecessary maintenance takes resources away from necessary maintenance
- Good maintenance programs undergo continuous improvement

… is vital to development, implementation, execution, and continuous improvement of an effective maintenance program.

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Section 3—What Comprises Maintenance?

It is important that we now consider, from the viewpoint of RCM, all the elements that comprise what we call "maintenance" by asking the question: "What is maintenance?"

Why would we ask such a fundamental question? Very simply, to ensure that we all have the same understanding of what maintenance actually accomplishes. If maintenance practitioners have different ideas of what maintenance *is,* they will also have different ideas of what it should *accomplish*. It would thus be very difficult to achieve a common approach to maintenance program design and execution across the Navy maintenance community. As a consequence, this handbook now begins a detailed examination of maintenance by establishing that foundation.

3.1 Definition of Maintenance

Let's review the Navy's definitions of "maintenance"

- The Navy's Maintenance and Material Management (3M) Manual NAVSEAINST 4790.8(series) defines maintenance as:
  - "Actions taken to ensure that systems, equipments and components provide their intended function when required."

Recalling the reasons one does maintenance, listed in Section 2.2, the top-level objective for a maintenance program can be stated as restoring or preserving reliability for minimum cost. Without a common understanding of what maintenance is, the paths taken to achieve that objective may differ, especially if they are built on folklore rather than on well-established concepts of maintenance engineering. The results can be confusion in maintenance terminology and the development of inapplicable or ineffective maintenance tasks and task intervals.

In this book, we use the following definition:

> **Maintenance is the set of actions taken to ensure that systems, equipments and components provide their intended *functions* when required.**

There are a few points worth emphasizing about this definition.

First, the primary focus of this definition is on maintaining the intended function of an item rather than its design performance. Many designs provide excess performance capacity or endurance as an inherent characteristic of the design. E.g., the pump selected for a system may be rated at 100 gpm when the system design requirement is only 75 gpm. Maintenance that is oriented to sustaining excess capability not needed for operations expends resources without benefit. This is not good maintenance practice.

Next, this definition requires the function being maintained to be available when it is required. Since certain functions, such as weapons firing and overpressure relief, may not be required continuously, there may be a need to verify their availability.

Finally, the terms "component, equipment, and systems" as used in this definition apply to hardware at the particular level where the analysis is being performed. This may be a system, a subsystem, equipment, or a component, depending on the specific preventive maintenance task being examined.

This definition also forms the basis for the definition of functional failure:

> **Functional failure is an unsatisfactory condition in which intended functions are not adequately provided.**

The manner in which functional failure is discerned is dependent on what type of function is involved. There are several classifications of function:

- **Active functions** require activity of an item; e.g., a pump provides liquid flow.
- **Passive functions** are not related to activity; e.g., a pump contains the working fluid.
- **On-line functions** are continuously provided during normal operations; e.g., distribution of electrical power.
- **Off-line functions** are not continuously provided e.g., inflation of a life jacket or firing a missile. Usually, they are activated by some infrequent action or event.
- **Evident functions** are those whose loss is observable by the crew during their normal operating routine; e.g., loss of refrigerant flow causes an increase in refrigerated space temperature.
- **Hidden functions** are not observable by the crew during normal operations. They are provided by an item for which there is no immediate indication of malfunction or failure; e.g., failure of a relief valve to lift.

3.2 Three Categories of Maintenance

We defined "functional failure" earlier as an unsatisfactory condition in which intended functions are not adequately provided. Within the boundaries of that definition, there are only three options open to the maintenance manager for dealing with those conditions, as shown in Table 3.1:

- **Corrective** maintenance – restores failed functions by accomplishing repair or replacement.

- **Preventive** maintenance – minimizes the opportunity for functions to fail through use of tests, inspections, adjustments, replacements, and routine actions such as lubrication.

- **Alterative** maintenance (also known as modernization) – eliminates unsatisfactory conditions by removing the cause of failed functions through redesign.

Maintenance tasks can be scheduled to accomplish the objectives of all three of these categories, but the basis for scheduling these tasks depends on the type of maintenance:

- **Corrective** maintenance tasks are performed on the basis of urgency of restoring lost functionality. We can't schedule a failure, but only how quickly it should be restored based upon its severity.

- **Preventive** maintenance tasks are scheduled on the basis of operating age, where operating age is described in units that represent a meaningful and appropriate measure of wear, which may vary from item to item.

- **Alterative** maintenance tasks are scheduled on a one-time basis since they are individual, one-time improvement actions.

The three types of maintenance are comprised of different types of tasks:

- **Corrective** maintenance tasks include troubleshooting, alignment, restoration, replacement, or calibration of components, subassemblies, equipment, or systems.

- **Preventive** maintenance tasks include diagnostic tests or inspections (for both evident and hidden functions), restoration or replacement of items regardless of current condition, replacement of operating consumables, and greasing or lubrication of components.

- **Alterative** maintenance tasks involve upgrades to the original design of the item (evolutionary change) or complete redesign of the item (revolutionary change). If the item cannot be redesigned to achieve improved reliability, perhaps a redesign would at least allow for an appropriate preventive maintenance task. Examples include Fleet Alterations and Program Alterations, formerly made up of Ship Alterations (SHIPALTs), Machinery Alterations (MACALTs), and Alterations Equivalent to Repair (AERs).

Table 3.1 summarizes primary characteristics of these three basic categories of maintenance.

Category	Corrective	Preventive	Alterative
Objective	Correct Unsatisfactory Conditions	Minimize Unsatisfactory Conditions	Eliminate Unsatisfactory Conditions <u>or</u> Allow for Preventive Maintenance
Characteristic Actions	Adjust or Align, Calibrate, Troubleshoot, Replace	Test or Inspect, Restore or Replace or Top Off Consumables, Grease, Lubricate	Modify (Evolutionary Change) or Upgrade (Revolutionary Change)
Scheduling	Planned or Unplanned	Planned (Recurring)	Planned (One Time)
Sample Tasks or Activities	Adjust, Align, Replace Components	Vibration Analysis, IR Imaging, Oil Analysis, etc.	Redesign Components, Equipment or Systems

(Table 3.1) Three Types of Maintenance.

The focus of this discussion of maintenance concepts now narrows from three categories of maintenance to the single category of maintenance that is of greatest interest to the readers of this handbook: **preventive maintenance**.

3.3 Five Types of Preventive Maintenance Tasks

There are five different types of preventive maintenance tasks as shown in Table 3.2

Task	Condition-Directed	Time-Directed Life-renewal	Failure Finding	Servicing	Lubrication
Action	"Renew life" (restore or replace) based on measured condition compared to a standard	"Renew life" (restore or replace) regardless of condition	Determine whether failure has occurred	Add/replenish consumables (e.g. windshield washer fluid)	Oil, grease or otherwise lubricate
Circumstance	Equipment characteristic corresponds to failure mode	Imminent wear out	Failure of off-line or hidden" function (e.g. Safety/protective devices)	Reduced level of operating consumables	Accelerated wear
Typical Tasks	Diagnostic Test, Material Condition Inspection	Discard and replace with new item	Inspection, Functional Tests	Top off consumables (e.g. fluids)	Lubricate

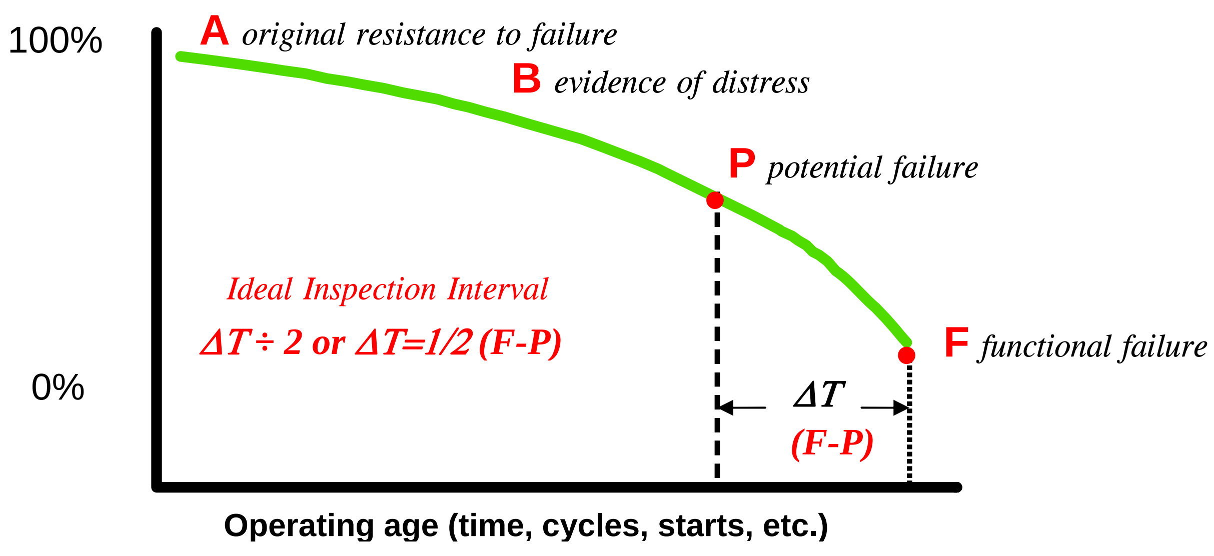
(Table 3.2) Five Types of Preventive Maintenance Tasks

Condition-Directed Tasks

A Condition-Directed (CD) task is a periodic diagnostic test or inspection that compares the existing material condition or performance of an item with established standards and takes further action accordingly. The purpose of condition-directed tasks is to discover a potential failure that can be corrected before actual failure occurs.

The logic behind this type of task is illustrated by the P-F (or potential failure – functional failure) curve of Figure 3.1. This figure illustrates the relationship between resistance to failure and operating age for an item from the point of initial introduction into service to the point of actual failure.

In the hypothetical example shown in Figure 3.1, a new bearing is placed in service with an initial resistance to failure near 100%. As the operating age of the bearing increases, its resistance to failure gradually decreases; that is, it experiences *age degradation*. At some point in the operating life of the bearing, the reduction in resistance to failure becomes evident, perhaps as an increase in level of vibration, a temperature increase, evidence of particulate matter, or a change of chemical or physical properties of lubricating oil. The bearing continues in service with increasing degradation and steadily decreasing resistance to failure until it reaches a point of potential failure, i.e., at which point a preventive maintenance action should be performed.



Source: Exhibit 3-1, *Reliability-Centered Maintenance,* Nowlan and Heap

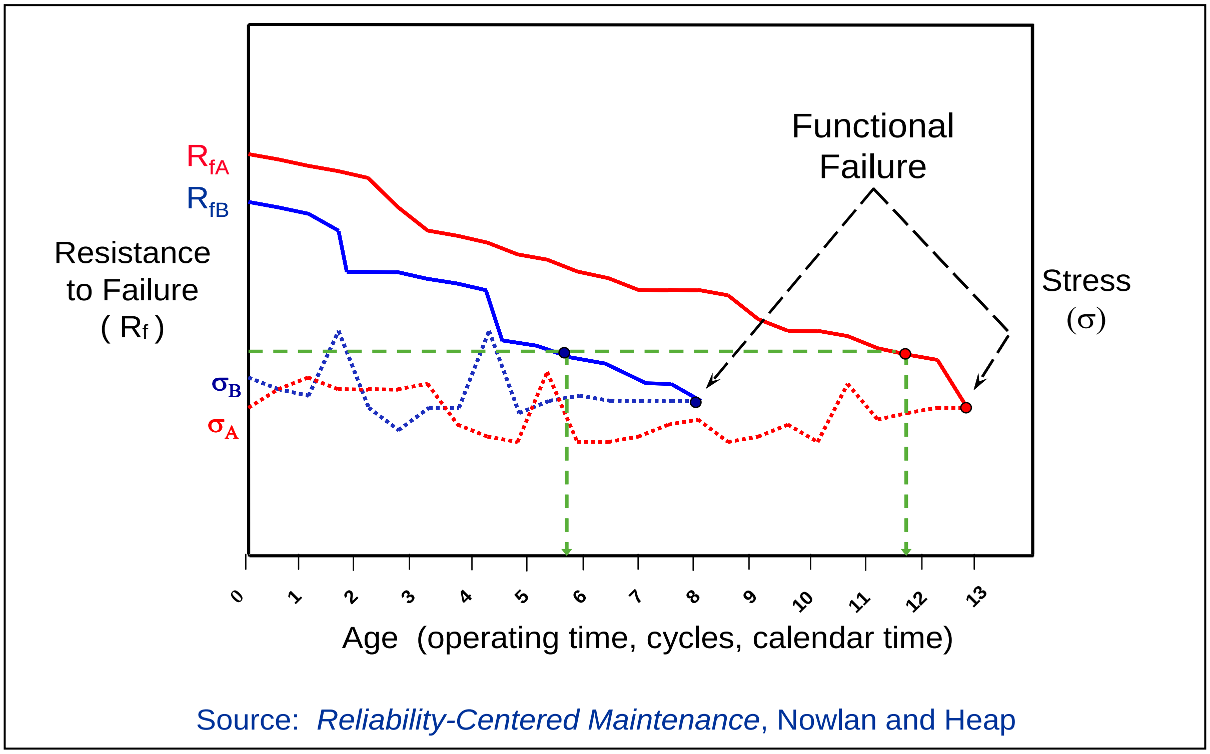
(Figure 3.1) P-F Curve

Two terms that are very important to good maintenance planning need to be examined carefully at this point.

The first term is "functional failure," which we defined as "an unsatisfactory condition in which intended functions are not adequately provided." Simply put, the item can no longer perform one or more of its' required functions. *Operating* standards determine satisfactory in service operation and should be used to define failure rather than *design* standards, which are used to define the acceptability of a new item.

The second term is "potential failure," which we define as an identifiable physical condition, which indicates a functional failure is imminent. The matter of whether or not an item is at the point of potential failure depends on how we define the potential failure. It is the result of measuring material condition or performance against a standard that determines whether the item is satisfactory, marginal, or unsatisfactory for service. Whenever a functional failure is defined in terms of performance, condition or dimension, the appropriate standards must be stated to provide the basis for determining when we are at the point of potential failure. Frequently, identical items will fail at different ages in service, as illustrated by Figure 3.2. This happens for several reasons, such as:

- Manufacturing tolerances
- Different lots or vendors
- Different operating profiles and stresses



(Figure 3.2) Like Items Fail at Different Ages.

What appears on the P-F curve as a point should really be shown as a range or a band of ages during which potential failure and actual failure are likely to occur. Further, no experienced maintainer will delay maintenance until the last possible point in time to take action: there are too many opportunities for problems to appear that will prevent effective maintenance and lead to actual failure at that point. The experienced maintainer will define potential failure in terms that will give him a reasonable length of time to take appropriate preventive action.

It is the specific conditions the maintenance planner must measure that will determine whether a condition-directed task can even be developed. If there are no conditions that provide an alert to failure, a condition-directed task is not possible. But once such conditions have been identified, one must identify the most appropriate standard to use that will identify an effective "go – no-go" point for continued operation. The next step is to determine what maintenance action, e.g., cleaning, adjusting, or life-renewal component replacement, can be taken to avoid imminent failure and to restore inherent resistance to failure. An important related step involves determining an adequate inspection interval (periodicity). While this is not an exact science, setting the inspection interval at one half the 'age measurement' between the potential failure condition and the functional failure condition (1/2 [F – P]), assures the analyst of conducting an inspection between potential failure and a functional failure.

If these conditions are satisfied, the maintenance planner will have a condition-directed preventive maintenance task for the failure. The tasks will be based on failure characteristics that indicate when action is required and what action is required.

Time-directed Life-Renewal Tasks

Time-directed life-renewal tasks restore or replace an item regardless of its actual material condition before the item reaches an age at which the probability of failure becomes much greater than at earlier ages. Such an increase in the probability of failure is called wear out.

The term 'time-directed life-renewal' is another way of naming a task that is performed solely on the basis of "age".

Age is described in units that represent a meaningful and appropriate measure of wear.

Time-directed life-renewal tasks are appropriate when there is evidence that most units of the population will end their service life at a specific age. At this point, something must be done to renew life before failure. The two typical actions taken to renew useful life of an item are:

- Restoration (also known as overhaul or rebuild), and
- Replacement

Life-renewal actions may pertain to systems, subsystems, equipment or components.

Determination of when an item has reached the end of its useful operating life and requires life-renewal is provided by evidence of an increasing and unacceptably high conditional probability of failure. Evidence of this condition is best provided by age-reliability analysis of failure data for the population of items in question. In theory, age-reliability analysis is needed to ensure that the whole population exhibits this phenomenon. The decision to use a time-directed life-renewal maintenance task is based primarily on two factors:

- The majority of the population of the item must exhibit an increased conditional probability of failure after some age has been reached; e.g., shelf life of batteries; and
- There must be no measurable condition that predicts failure; i.e., there is no condition-directed task

Replacement of an item as a life-renewal task is straightforward: the "worn out" item is exchanged for a completely new item.

Restoration of an item may take many forms. The complete overhaul or rebuild of an item is a restoration action — but so is the cleaning of a dirty filter. Both actions restore the item to "like new" condition even though the extent of effort required is dramatically different. Replacement of a component, subassembly, or assembly within an item is also a restoration action where that component, subassembly, or assembly has a definite operating life and its failure causes loss of item functionality. For this case, the term "life-renewal" applies to the component, subassembly or assembly and not to the complete item. The complete item can be said to have "worn out" when many internal components of the item have similar age-reliability characteristics and must be replaced in the same general time frame. Time-directed life-renewal tasks are performed regardless of the actual condition of the item. There is an appropriate place for this type of task in a well-designed maintenance program where objective evidence exists that an item has reached wear out, or the point at which an item has no service life remaining and it must be completely rebuilt or replaced. Applying this type of task without such evidence, however, would be like replacing tires at a given mileage regardless of remaining tread. Such action would renew the tire's resistance to failure, but for a price that is greater than the required cost, and is thus unacceptable.

Failure-Finding Tasks

Failure-finding tasks are used to evaluate the condition of off-line or intermittent-use functions whose failures would be hidden from the operating crew. These functions are most often associated with safety or protective devices whose condition is not known without testing and whose service is infrequent. These functions are also associated with items that are used only intermittently, such as weapons systems, emergency diesel generators, or redundant items that provide the same capability. Because functional failure of both off-line and intermittent-use items are not evident to the operating crew during routine operations, their functions must be tested or inspected periodically to be sure they are still available for operation when needed.

Failure-finding tasks do not prevent hardware failures — they discover hidden failures that have already occurred.

Failure finding tasks can prevent multiple or cascading failures that can result from the failure of a hidden function. The conditions surrounding the use of off-line or intermittent use functions — such as those provided by safety or protective devices — are very different from those surrounding on-line (or evident) functions.

In the first place, these items may be used infrequently, and there is unlikely sufficient failure data available for analysis to help set maintenance task periodicity.

Next, the requirement for these safety or protective devices to function is generally initiated by the failure of an evident function — some item that may be already covered by preventive maintenance designed to minimize its opportunity for failure. Thus, for the hidden failure to become evident, multiple failures must occur. The probability of a multiple failure is the product of the individual probabilities of each failure involved, generally a very small number. Even though the composite probability of failure may be extremely low, the severe consequences of some multiple or cascading failures may warrant periodic testing.

Some maintenance planners take a very conservative approach to developing and scheduling failure-finding tasks because of the potential severity of the multiple-failure situations they are designed to prevent. Even though the severity of failure may be enormous, the probability of multiple failures is so low that, these tasks often afford a reasonable opportunity for improvement in task scheduling with little or no increase in risk.

Servicing Tasks

Servicing tasks "top off" or replenish operating consumables that are required for normal operations. Examples include such tasks as filling a windshield washer reservoir or adding paper to a printer. Such tasks are very straightforward operating duties for assigned personnel and as such are not normally codified as scheduled tasks in the Planned Maintenance System.

Lubrication Tasks

Lubrication tasks specify routine greasing and lubricating of rolling or sliding surfaces in contact or the application of a grease or lubricant to stationary surfaces to provide protection from the environment. Such tasks do not require extensive justification but should be evaluated for adequacy.

Note: Servicing and Lubrication Tasks are preventive maintenance tasks that can be either condition-directed or time-directed, but are treated as separate types of tasks using a simplified analysis form.

Non-Maintenance Tasks

Now that we have discussed the five basic types of preventive maintenance tasks, we need to discuss non-maintenance tasks that might creep into the PMS package. What tasks might you find in the Planned Maintenance System that are **not** valid preventive maintenance tasks?

One example is data collection. An MRC may be proposed to have a Sailor copy meter readings and mail them to some data collection site. Another example is backing-up a computer hard drive. This is the electronic equivalent of making a Xerox copy of the paper files in your desk. Yet another example of non-maintenance is routine cleaning, such as cleaning the exterior surfaces galley equipment or electronics cabinets. All of these actions may be useful in some fashion, but they do not prevent functional failures, and should not be considered maintenance. Consequently, they should not be placed in the Planned Maintenance System. If they must be performed, there are other means to do so, including routine watchstanding procedures, zone inspections, CSOSS or EOSS, logkeeping, etc.

While this handbook is concerned specifically with the development and improvement of RCM-based preventive maintenance tasks, it is important to note that the PMS system does include other valid Integrated Class Maintenance Plan (ICMP) assessment procedures and repair procedures not normally accomplished by ship's force. The development, review, approval, and use of ICMP procedures are beyond the scope of this book.

3.4 Summary

Maintenance consists of all actions taken to ensure that components, equipment, and systems provide their intended functions when required. By concentrating on *intended* functionality the maintainer ensures resources are not wasted on maintaining functionality in excess of those required.

All maintenance actions can be classified into one of the following categories:

- **Corrective Maintenance** – Restore lost or degraded function
- **Preventive Maintenance** – Minimizes opportunity for function to fail
- **Alterative Maintenance** – Eliminate unsatisfactory condition by changing system design

The only significant difference in the three types of maintenance is the reason why each is accomplished resulting in differences in when each is scheduled for performance.

Within the category of preventive maintenance all tasks accomplished can be described as belonging to one of five (5) major task types:

- **Condition Directed** – Renew life based on measured condition compared to a standard
- **Time Directed** – Renew life regardless of condition
- **Failure Finding** – Determine whether failure has occurred
- **Servicing** – Add/replenish consumables
- **Lubrication** – Oil, grease or otherwise lubricate

Tasks which cannot be classified as one of these major types are not really maintenance tasks.

Section 4—The Rules of RCM

Now that we have established what maintenance is, we will use an organized approach to identify and update good maintenance requirements.

We have defined what maintenance is, established its objective, and explored the different types of maintenance. Now, how can we determine whether or not we are doing the correct maintenance?

As noted previously, this question faced airline executives who were responsible for aircraft maintenance in the late 1950s and early 1960s. For decades their aircraft maintenance plans had been based on the assumption that every repairable item in the aircraft had a natural service "life" that could be measured in calendar time or operating hours. When an item came to the end of its "life," it was time for overhaul or replacement.

This approach to maintenance came under close scrutiny in the late 1950s, leading a senior vice president of United Airlines to ask his principal assistants, "Why do we do maintenance?"

4.1 Three Hypotheses

When they consolidated their thoughts, these airline senior managers developed a single sentence statement of why they were doing maintenance:

> **We do maintenance because we believe that hardware reliability degrades with age, but that we can do something to restore or maintain the original reliability that pays for itself**.

This single statement contains three hypotheses:

- *The first hypothesis is that an item's operating reliability degrades with age.* Maintenance must be based on age degradation. There is no good reason to invest maintenance resources in an item whose operating reliability does not or will not degrade with age.

  Age degradation is a reduction of the item's operating reliability caused by reduction of the item's resistance to failure as it is used. Since Reliability is defined as one minus the Probability of Failure (Rel = 1 – P_f), we can also say it's an increase in P_f with use.

- *The second hypothesis is that maintenance exists that can restore or maintain original reliability.* There is no good reason to accomplish maintenance that has no effect on the hardware or that even increases its probability of failure.

- *The third hypothesis is that maintenance "pays for itself,"* i.e., the value of the maintenance must exceed its *cost*. There is no good reason to spend more resources on maintenance than one would expect to spend to correct the effects of failure, where safety and mission impact have been considered.

This statement and its hypotheses are valid for every maintenance task. Each maintenance task, whether for ship or aircraft systems or equipment, must satisfy each of these three hypotheses to claim a place in a well-designed maintenance program.

Let's take a closer look at each of these hypotheses.

First, hardware reliability must degrade with age for maintenance to be considered as an option. Does everything degrade with age? Yes. Does degradation always cause a problem with reliability? No. Some items degrade so slowly with age that they will be discarded or replaced for some other reason before degraded reliability becomes a problem. It is the rate of age degradation during the life of the item that is the key issue here. The rate of age degradation must be sufficient to create concern for maintenance managers.

Recall that age is described in units that represent a meaningful and appropriate measure of wear.

It's important to note that 'age' may not always be measured in terms of calendar time. Age may be measured in such terms as rounds fired, equipment cycles, miles traveled, operating hours, or calendar time.

Second, maintenance must restore or maintain the item's original reliability. In other words, the specified maintenance must be **applicable (relevant)**. The maintenance analyst needs knowledge of failure characteristics to make this judgment.

Failure characteristics are the conditions that describe how the item fails. For example, does the item fail rapidly or slowly? Does the item provide any indications of distress before it fails? Are these indications representative of the population as a whole? Can they be measured, and is their measurement reliable?

Compare the failure characteristics of a printed circuit board (e.g., instantaneous, random failure) with the failure characteristics of a centrifugal pump (e.g., slow decrease in output to an unsatisfactory flow rate). What are these failure characteristics, and is each failure characteristic preventable? How could you prevent the failure characteristics from developing?

Sometimes an examination of failure characteristics reveals the need for a design change rather than preventive maintenance if the inherent reliability of the item should be improved. Certain failure characteristics are inherent in the item by design and can be changed only through design change.

Finally, maintenance tasks must be **effective** (**have value)** relative to failure consequences. Since not all failures have the same consequences, the measure of value may be different for different tasks. The difference in failure consequences (safety, environmental, mission, and economic) — and the different measures of maintenance task value that relate to these different consequences — are described in greater detail in Section 4.3 of this handbook.

4.2 All Maintenance Tasks Must Be Applicable (Relevant)

Maintenance tasks must restore or maintain the inherent reliability of the item. An applicable task is one that really prevents, discovers, or reduces the impact of the failure mode in question. Some tasks, however, either have no effect or have an adverse effect on reliability. These tasks are not applicable to a well-designed maintenance program because they fail to have the desired result.

The Reliability-Centered Maintenance methodology includes rules for determining whether three types of preventive maintenance tasks (condition-directed, time-directed life-renewal, and failure-finding tasks) are applicable. The two other types of preventive maintenance tasks (servicing and lubrication)— do not require formal rules since:

- Servicing tasks are straightforward and do not require special analysis: operating consumables must be replaced before they reach levels that cause functional failures.
- The requirement for lubrication is evident for situations that involve rolling or sliding friction. The requirement for grease should be evident here as well as for situations where exterior corrosion may present a problem.

There are three rules for determining the applicability or relevance of condition-directed tasks, age-directed life-renewal tasks, and failure-finding tasks.

Condition-Directed Task Rules

1. An equipment characteristic corresponding to the specific failure mode can be identified.
2. That characteristic can be measured accurately and with consistency.
3. Sufficient time exists between the identification of potential failure and actual failure to take corrective action to prevent failure.

Time-Directed Life-Renewal Task Rules

1. The conditional probability of failure increases at a specific age (evidence of "wear out").
2. A large proportion of the population must survive to the point of "wear out".
3. There must be no condition that predicts failure.

Failure-Finding Task Rules

1. The functional failure must not be evident to the operating crew during routine operations.
2. The failure-finding task determines whether or not the intended function is available.
3. No appropriate condition-directed or time-directed life-renewal task can be devised to prevent failure.

All three of the applicability rules associated with a given type of task must be satisfied for each task being analyzed for the task to be applicable. If the task fails to satisfy ***any*** of its rules, it is not applicable, and may not be used as is.

Failure of a proposed task to satisfy one or more of the appropriate rules does not necessarily mean the task has no inherent value. Rather, failure to satisfy a rule may mean that some change is required to the task as currently presented that will make it applicable. These rules do more than simply serve as a "go – no-go gage" for task evaluation. They also serve as diagnostics to improve tasks as they are currently formulated.

These rules of applicability are used to determine whether the choice of task was correct. The required result, of course, is for each task to restore or maintain the inherent reliability of the item. That is a basic reason for maintenance. It is not, however, a sufficient reason. Each proposed task must also be worth doing.

That leads us to the fifth maintenance concept.

4.3 All Maintenance Tasks Must Be Effective (Have Value)

Applicable preventive maintenance tasks minimize failures, but not all failures are worth preventing. Expressed differently, how do we determine whether the maintenance tasks we are performing are effective, i.e., have value?

The term "value" implies worth: a measure of importance that exceeds a given cost. Since all maintenance actions have an associated cost, it is not unreasonable to expect the worth of the maintenance to exceed its cost.

Effective tasks have value and, therefore, may be worth doing.

Now, how do we determine whether tasks are effective and really worth doing?

The determination of whether a task is effective requires examining the failure consequences. Not all failures have the same consequences:

- Some failures can result in injury or death. Tasks that prevent failures that seriously injure or kill someone have great value.
- Some failures may violate federal, state, or local regulations such as those related to protection of the environment. Tasks that prevent these failures also have great value.
- Other failures can substantially impair a ship's ability to carry out its assigned missions. Tasks that prevent failures causing the loss of a primary mission capability are very valuable.
- All other failures are evaluated on the basis of economics.

Maintenance is an investment. The issue is one of measuring the return on investment for the maintenance performed. The following criteria are used to determine priorities for maintenance task accomplishment as well as for determining whether they are at all worth doing. In very simple terms, to be effective:

- Tasks for failures that affect personnel safety or the environment must reduce the *probability* of failure to an acceptable level;

- Tasks for failures that affect ship mission capability must reduce the *risk* of failure to an acceptable level;

- Tasks for all other failures must cost less to accomplish than the cost of repairing the failure plus the cost of the lost capability.

Maintenance programs must change and adapt to take advantage of experience that is gained in service and to meet new operational requirements that may be imposed on the ship. A maintenance program that is developed, installed in a ship, and never changed during the normal life of the ship is almost certain to be ineffective in a number of different areas.

Thus we have our sixth and final maintenance concept that establishes the foundation for good maintenance throughout the Navy.

4.4 Why We Need RCM Methodology

Resources spent on maintenance represent an investment. This investment should pay a dividend in sustained equipment reliability, operational availability, and avoidance of costs associated with failure. Good maintenance planning is required to ensure that the correct balance is achieved between investment and results, just as it is in the case of financial planning.

Once we realize that maintenance is an investment, our objective becomes maintenance that will maximize our return on that investment. We know further that wise investors understand the principles that apply to investing, and they use rules to guide them in evaluating opportunities. The same applies to maintenance. Maintenance principles exist that govern the development of effective maintenance programs. There are rules to follow that ensure the analyst, planner, or manager is working effectively within those principles. The principles form the basis for the rules, and the process for applying the rules properly becomes a methodology for guiding the maintenance planner. Without rules built on principles and a methodology that applies the rules, the maintenance planner is vulnerable to being misled by unfounded past practices as he builds a maintenance program.

4.5 Summary

In the 1950s it was asked, "Why do we do maintenance." The answer to this was a simple statement; "We do maintenance because we believe that hardware reliability degrades with age, but that we can do something to restore or maintain original reliability that pays for itself."

Out of this statement grew the tenants of RCM. The RCM methodology ensures that every task is generated only in response to a problem (failure mode) and that the solution developed actually does improve or maintain reliability and is worth doing.

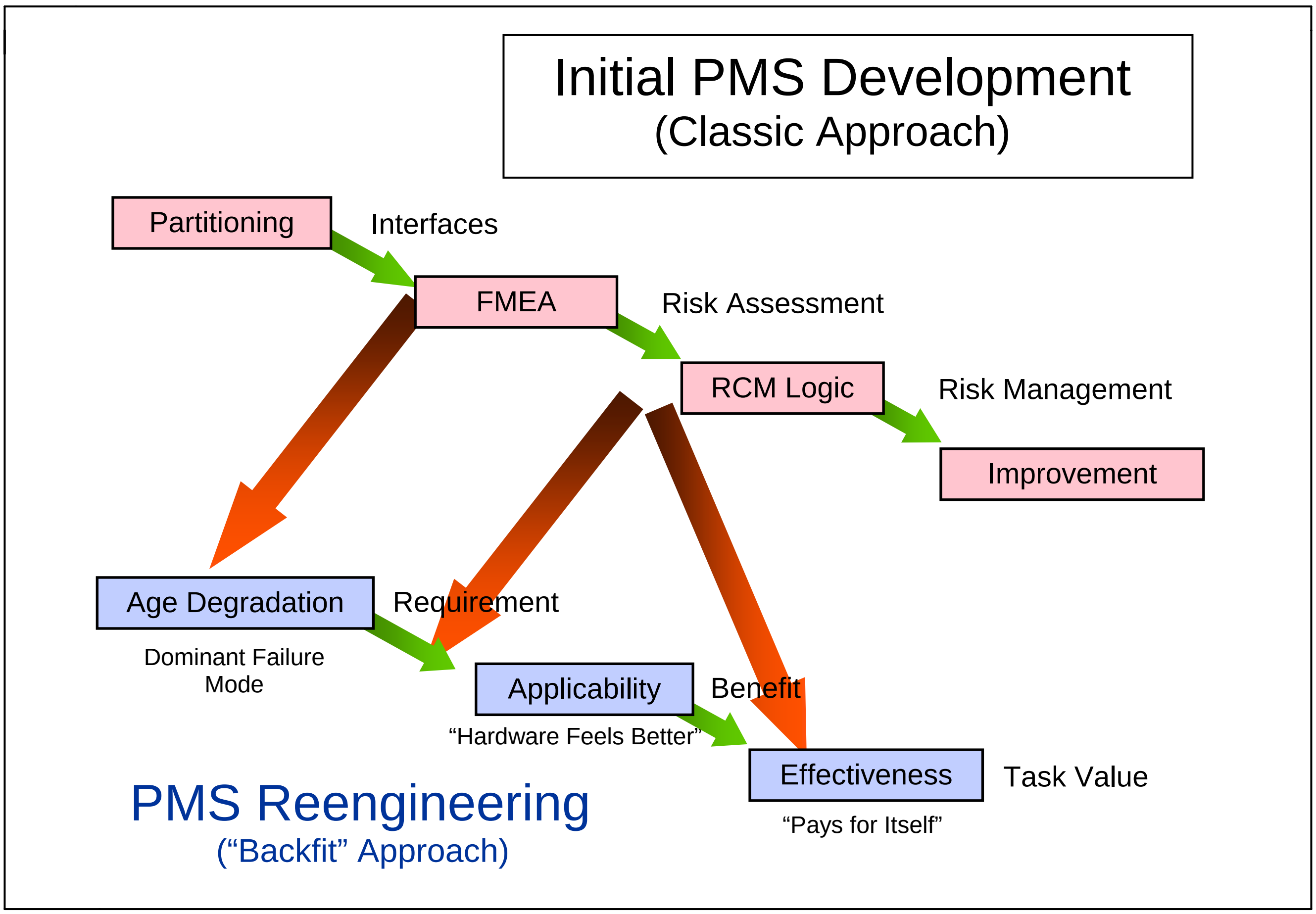
Every task must be determined if it is "Applicable" and "Effective". An applicable task is one that really does prevent, discover, or reduce the impact of a particular failure mode. Whether a task is applicable is determined by meeting the specific rule for the type of task that is to be performed.

Effective tasks are worth doing. Once a task has been determined to be applicable it needs to be determined if it's worth the expenditure of the resources needed to accomplish it based on the consequences of the failure happening.

By applying the RCM methodology, it is ensured that careful thought has been given to every defined task. Every task generated is guaranteed to address a problem of concern (dominant failure mode), actually address that failure mode with a solution that accomplishes something, and that the expenditure of resources toward accomplishing that task is more beneficial than simply allowing the failure to occur.

Section 5—Two RCM Processes

Figure 5.1 illustrates the functional relationship between the Classic RCM and Backfit RCM processes. Classic RCM is a methodology that carefully develops, analyzes and documents requirements thoroughly as it proceeds to develop a maintenance program in an environment of uncertainty with limited operating data. Backfit RCM applies where sufficient operating data exists to confirm assumptions that were made when the original maintenance program was developed, validating existing maintenance requirements or recommending changes as appropriate. Classic RCM provides a technique for dealing with the uncertainty of maintaining new equipment for which no operating history exists. Backfit RCM provides a technique for dealing with the uncertainty of changing existing, satisfactory maintenance requirements to make the maintenance program even more effective.



(Figure 5.1.) Comparison of Two RCM Processes.

We begin a brief comparison of the two approaches in Figure 5.1 with the four basic steps of the Classic RCM process:

- *Partitioning* identifies all the constituent parts of the item to be analyzed, and defines the interfaces between these parts;
- *FMEA* (or failure modes and effects analysis) conducts a risk assessment of functional failures and eliminates those with acceptably low risk values from further analysis;
- *RCM Logic* tree applies risk management to surviving functional failures based on failure consequences; and
- *Age exploration* ensures continuous improvement by testing and evaluating the limits of *maintenance* tasks.

Now we shift our focus to Backfit RCM.

Backfit RCM uses both the analytical work done in developing the original maintenance requirements package and the item operating experience gained since the maintenance program has been in service to validate the quality of maintenance. Backfit RCM does not duplicate Classic RCM; it uses the knowledge gained from operating and maintenance experience to validate assumptions made when the original program was developed.

The first step of the Classic RCM approach, Partitioning, is not duplicated in the Backfit approach, since the system partitioning has already been factored into the existing PMS.

The first step of Backfit RCM, age degradation, validates the FMEA decisions of the second step of the Classic approach. The Backfit RCM analyst will use the operating history for the item to determine whether the original selection of dominant failure modes was correct. The results of this determination will either confirm or refute evidence of reliability degradation. If there is evidence of reliability degradation, the analyst will proceed to the second Backfit RCM step; if not, he or she will recommend deletion of the maintenance task.

The second and third steps of the Backfit approach (assessment of Applicability and Effectiveness) correspond to Classic RCM application of the RCM Logic tree. For both Applicability and Effectiveness, the action of the Backfit RCM analyst is to assess the validity of the basis for the current tasks and to recommend action as appropriate. Operating experience identifies actual dominant failure modes for age degradation validation; the Decision Logic provides tasks that should satisfy the criteria for maintenance task relevance and value. This assessment determines whether or not the maintenance task, as written, does serve to prevent the intended failure and does so in a cost effective manner. If the answer to either question is no, the task may be eliminated or, if appropriate, revised in scope and/or periodicity.

5.1 Summary

Reliability-Centered Maintenance is created around the fundamental tenants of what makes good maintenance. All tasks should address real problems (dominant failure modes), actually accomplish something (applicable), and be worth accomplishing (effective). In order to apply these concepts consistently over the entire lifecycle of a system two approaches are necessary.

Classic RCM provides a process around which initial maintenance actions can be developed using the best judgment of expected functional requirements, expected failures and maintenance capabilities.

Backfit RCM provides a straightforward means of validating the existing maintenance requirements of the system after more experience has been gained with the equipment. It ensures that any changes we make to maintenance requirements as part of the continuous improvement process are grounded in the fundamental tenants of what makes for ‘good’ maintenance.

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Section 6—The Classic RCM Process

This section describes the steps taken and the forms used to develop an RCM-based maintenance program for new ship systems. Emphasis is placed on the RCM analysis aspect of the process. Most form development details are referred to the appropriate paragraphs of MIL-P-24534A.

The objective of applying Classic RCM to a system, its subsystems, and equipment is to:

- Determine the applicable (relevant) and effective (value added) preventive maintenance required to protect against dominant failures, both evident and hidden
- Develop the necessary detailed directions for accomplishing the maintenance
- Develop a recommended schedule (periodicity) of maintenance actions

Applicable Planned Maintenance System documentation is defined by OPNAVINST 4790.4 (series) and developed in accordance with MIL-P-24534A and this Handbook.

6.1 Analyst Selection and Training

The Naval Sea Systems Command is the technical authority for Planned Maintenance task determination. Optimal development of RCM-based maintenance is best accomplished by the application of three different skills:

- An understanding of the system's design from the viewpoint of the designer (an Original Equipment Manufacturer (OEM), shipbuilder, or Navy in-service engineer)
- An understanding of how the system is, or will be, used, and of its dominant failures and operating characteristics (a Navy ship's work center supervisor operator/maintainer)
- An understanding of in-service reliability analysis and preparation of maintenance requirements documents (an OEM, shipbuilder, or Navy reliability analyst)

The most effective applications of RCM result when persons having these skills work together. An effective way to achieve this objective is to assign two-man engineer/shipboard technician teams to work on systems familiar to them and, if practicable, have the hardware available. A reliability specialist who serves all teams on a particular project can provide the third skill.

The staff also includes the associated PMS Coordinating Activity commodity specialist who reviews all documents to ensure that they are technically correct and comply with the applicable standards and specifications prior to Navy issue.

Those preparing, reviewing, accepting or approving an RCM-based preventive maintenance program require training and NAVSEA certification in RCM concepts and methodology and in use of the documentation specified in MIL-P-24534A as explained in Section 1.4. This training must be accomplished through the NAVSEA RCM Certification Program administered by SEA 04 for all Navy and contractor personnel involved with development, review, acceptance or approval of PMS tasks. It is also important that members of the team become very familiar with the design, operating characteristics, and operating experience of the systems assigned. Periodic meetings of all teams on the project to discuss ideas and problems associated with each documentation step in the RCM process will accelerate the learning process and avoid many potential pitfalls.

Preparing maintenance requirements using an RCM-based program is intended to be an innovative, creative search for applicable and effective tasks.

6.2 Information Collection

The analyst should gather necessary technical information for each ship system and its equipment.

- Descriptive information:
  - Narrative descriptions
  - Design specifications
  - System schematics (including interfaces with other systems)
  - Assembly drawings
  - Field and engineering changes

- Operating information:
  - Operating and maintenance instructions
  - Condition and performance standards
  - Failure data
  - Existing Maintenance Index Pages (MIP) and Maintenance Requirement Cards (MRC) for similar systems (for use as a source of information after tasks have been identified and as a check that all dominant failures have been identified)

6.3 System Partitioning and Identification

A major task of the ship design team involves identification of all ship systems and partitioning of the design in a logical way, using the Expanded Ship Work Breakdown Structure (ESWBS). ESWBS is an equipment or lower level of indenture than the Ship Work Authorization Boundary (SWAB). (See Table 6-1.)

The RCM analyst begins with the SWAB and goes to the lower levels of indenture only as needed. (See example in Table 6-2.) Analysis seldom needs to be made to the piece part level.

The Webster's Unabridged Dictionary defines a system as a group of independent but interrelated elements comprising a unified whole. This definition permits two quite different perceptions -- unified as a collection of like things (e.g., a collection of all antennas) or as an organic assembly (e.g., a fuel system). The organic approach simplifies analysis since it links system inputs to outputs. The collection of 'like things' approach may put inputs in one system and outputs in another.

No matter how the analyst decides to structure each system, it is necessary to ensure that the analyst and final technical reviewer agree on the content and structure of each system before proceeding.

Table 6-1: Ship Work Breakdown Structure

SWAB Group	Nomenclature	General Scope
100	Hull Structure	Ships structure including decks, stacks, foundations, and superstructure
200	Propulsion Plant	Systems and subsystems to support propulsion
300	Electric Plant	Electrical generation and distribution equipment
400	Command and Surveillance	Systems for command control, navigation, tracking and fire control
500	Auxiliary Systems	Fluid, electromechanical, air conditioning and ship support systems
600	Outfit and Furnishing	Habitability and sanitary systems, furnishings, and services
700	Armament	Offensive and defensive weapon systems

Table 6-2: Example of SWAB Indenture

500	AUXILIARY GROUP	Level 1 -- Major Functional Group
510	CLIMATE CONTROL	Level 2 -- Functional Subgroup of System
514	AIR CONDITIONING SYSTEM	Level 3 -- Systems and Elements
5141	WATER, CHILLED, COOLING DISTRIBUTION	Level 4 -- Subsystem and Sub-element
5141-1	WATER, CHILLED, COOLING PUMP	Level 5 -- Component and Equipment (Level 4 + unique identifier)

6.4 Systems Analysis

The RCM method requires analysis of preventive maintenance requirements at the system and subsystem levels. The need for analysis below the subsystem level will be determined later in the process and depends on the complexity of the system and the analyst's knowledge and expertise. It is often unproductive to go below the subsystem level. Nevertheless, understanding all of the functions of a complex system and selecting applicable (relevant) and effective (value added) tasks to maintain them may require selective detail at the equipment level or below.

Keep in mind that the system level often provides an opportunity for operational checks (condition-directed or failure finding tasks) that are very effective. Do not overlook this opportunity.

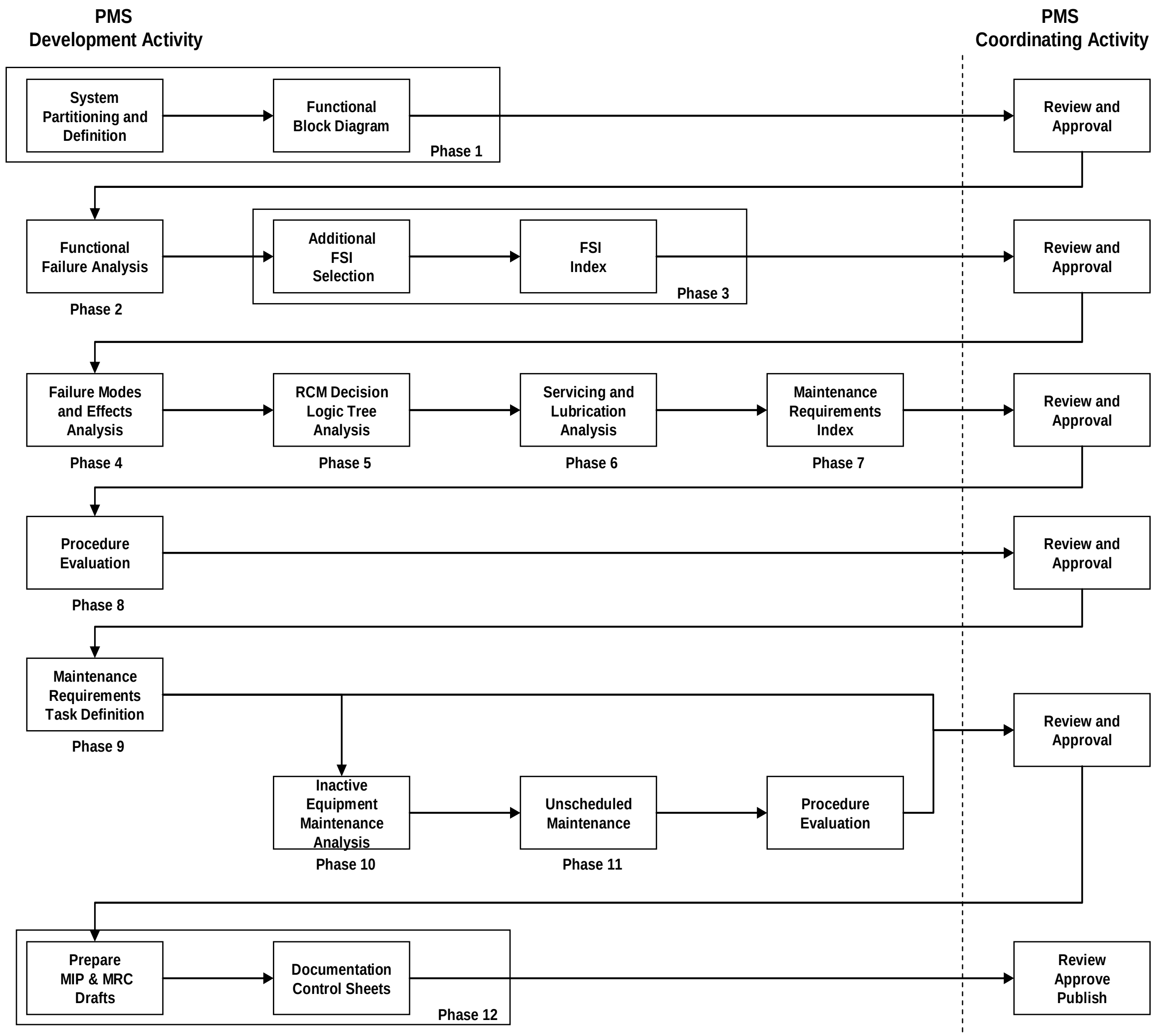
6.5 The RCM Methodology

In previous sections, we have discussed a wide range of things -- history, principles, and types of tasks -- but we have not yet detailed a method for using the knowledge we have acquired. If one can keep what has already been discussed clearly in mind, it can improve one’s ability to develop maintenance programs. But an important piece of the puzzle is still missing. We need an orderly method for using the knowledge we now have about preventive maintenance.

Analysts will build a list of functional failures and failure modes by describing each system/subsystem, and by listing its functions (both evident and hidden), its input and output interfaces, and its functional failures. For complex systems or subsystems, analysts may break some lesser items out separately to obtain similar, more detailed, information for each of these items.

6.6 Designing an RCM-Based Preventive Maintenance Program (MIL-P-24534A)

The required RCM-based methodology for developing a preventive maintenance program uses a process consisting of 12 phases. The flow of these phases is shown in Figure 6-1 and detailed in Table 6-3. The review and approval requirements are also shown in Table 6-4.



(Figure 6-1) 12 Phase Process

6.7 Phase 1: Functional Block Diagram and the Master Systems and Subsystems Index (OPNAV FORM 4790/114, Appendix B-1)

This phase involves preparation of a system or subsystem Functional Block Diagram (FBD). The primary purpose of the functional block diagram is to ensure that the analyst determines all of the functions provided by the system and within the system so that functional failures can be determined and analyzed. The FBD shows all system components, their functional relationships to one another, and the incoming and outgoing interfaces with other systems. Out interfaces represent active functions. Passive functions, such as containment of fluids, may be internal to the functional block diagram. For purposes of failure analysis, the analyst assumes that all incoming functions are available.

The other necessary action is the development of a master index to define a set of mutually exclusive and exhaustive development assignments. The Master Systems and Subsystems Index is based on the Ship Work Authorization Boundary (SWAB), taken to the necessary level of indenture. SWAB has been replaced by the more detailed breakdown called ESWBS. Use of ESWBS structure will satisfy MIL-P SWAB requirements fully.

Detailed instructions on completing the MSSI Form are contained in MIL-P-24534A paragraph 3.7.2.2.

Table 6-3: MIL-P-24534A Planned Maintenance System Development

Phase	Description	Purpose	Mil-P Paragraph	OPNAV Form 4790/
1	Partitioning: Functional Block Diagram and Master System & Subsystems Index (MSSI)	Determine system boundaries, interfaces, and functions.	3.7.2	114
2	Functional Failure Analysis (FFA)	Describe system/subsystem, functions and interfaces. Identify active and passive failures.	3.7.3	116
3	Additional Functionally Significant Item Selection (AFSI) and Functionally Significant Item Index (FSII)	Identify functions and functional failures at levels of indenture below the subsystem. List all FSIs in SWAB order.	3.7.4	117 & 118
4	Failure Modes and Effects Analysis (FMEA)	Determine dominant failures. Identify the effect (consequences) of failure.	3.7.5	119
5	RCM Decision Logic Tree Analysis	Identify need for maintenance task. Determine whether or not proposed task is applicable and effective.	3.7.6	120
6	Servicing and Lubrication Analysis	Use in lieu of Step 5 to evaluate routine servicing and lubrication requirements.	3.7.7	121
7	Audit and Preparation of the Maintenance Requirement: Maintenance Requirement Index (MRI)	List all proposed maintenance tasks for review and approval.	3.7.9	123
8	Method Study and Procedure Evaluation for New Tasks and Revised Maintenance Requirement Cards (MRCs)	Develop the most practical method of accomplishing each task.	3.7.10 and 3.10	130
9	Maintenance Requirements Task Definition	Determine appropriate maintenance level (O, I, or D)	3.7.11	124
10	Inactive Equipment Maintenance (IEM)	Develop procedures to layup, preserve, reactivate, and test inactive equipment.	3.7.12 and 3.10	129
11	Unscheduled Maintenance Documentation	Develop procedures for returning systems/equipment to service following corrective maintenance.	3.7.13 and 3.9	NA
12	Maintenance Index Page (MIP) and Maintenance Requirement Card (MRC) Development and Preparation	Prepare MIPs and MRCs	3.7.14 3.11 and 3.12	85

Table 6-4: MIL-P-24534A PMS Development Review and Approval

PMS Development Activity Package Submittal		PMS Coordinating Activity Action
Phase 1:	Functional Block Diagram	Review and approval
Phases 2 and 3:	FFA and AFSI/FSI	Review and approval
Phases 4 – 7:	FMEA, RCM Decision Tree Analysis, Servicing and Lubrication Analysis, and MRI Audit	Review and approval
Phase 8:	Procedure Evaluation	Review and approval
Phases 9 and 10:	Maintenance Requirements Task Definition and Inactive Equipment Maintenance Requirements Analysis	Review and approval
Phases 11 and 12:	Unscheduled Maintenance Documentation and Verification of Drafts and Document Validation	Review and approval

After development assignments have been made, it is possible that this index (and the related source) will require revision as the result of additional information obtained by analysts during the development process. Probable causes for these revisions are:

- A system contains different equipment items from those shown in preliminary design documents
- Equipment items have been shown in the wrong system
- A system was perceived as a "set of things" (such as antennas) rather than as a source of functions

Such revisions should be discussed with the PMS Coordinating Activity.

In some cases the analyst will be developing maintenance for a single, simple, piece of equipment, not comprised of many systems or functions. In such cases the partitioning (Phase I) and Functional Failure Analysis (Phase 2) may be bypassed with permission from the PMS Coordinating Activity. Development will begin with the functionally significant item selection, Phase 3.

6.8 Phase 2: Functional Failure Analysis (OPNAV FORM 4790/116, Appendix B-2)

A Functional Failure Analysis (FFA) is required for most RCM applications. For single equipment applications, the partitioning and functional failure analysis phases can be bypassed in accordance with MIL-P-24534A, paragraph 3.6.5.6. Development for these applications with the PMS Coordinating Activity permission can begin with the functionally significant item selection, phase 3. For all other RCM applications, analysts will prepare an FFA for each system and subsystem listed in the Master Systems and Subsystem Index. The purpose of each FFA is to:

- Provide a functional description of each system and subsystem
- Identify all functions
- Identify all interfaces with other systems
- Identify all functional failures (including failures of output interfaces)

MIL-P-24534A, paragraph 3.7.3.4, provides detailed guidance for performing this task.

If a system is simple (i.e., no subsystem breakdown necessary), only a single FFA is required. This FFA will, completely describe the characteristics of the system that must be considered for potential preventive maintenance tasks.

In preparing the FFAs, the analyst should evaluate the Functional Block Diagram prepared in Phase 1 to identify the functional elements of the entire system and the interfaces between it and other systems.

The FFA requires a brief narrative functional and physical description of the system, subsystem, or component. The purpose is to learn enough about each system to identify potential sources of system functional failures and provisions for maintenance. The description includes the following:

- Redundancy features, such as duplicate pumps
- Protective devices, such as relief valves
- Safety features, such as interlocks
- Fail safe or unsafe conditions and features
- Condition indicators, such as pressure gauges (documenting the type, what it indicates and to whom)
- Environment in which the system operates
- Duty cycle, e.g., continuous or intermittent
- Use restrictions; e.g., not to be operated in port
- Special maintenance features

Identification of all functions requires careful study, making sure to include important passive functions. It is important to recognize that loss of a passive function may be significant, even though the system may be off line at the time of failure.

A functional failure exists when a system or subsystem doesn’t provide a required function adequately or at all. That is, a functional failure is an unsatisfactory condition. Note that some functions are active (loss of the required activity constitutes failure) while some are passive. For example, a centrifugal pump can fail by not providing fluid flow at some rate and pressure (failure of an active function); it can also leak (failure of a passive function). Include failures of both kinds in this analysis.

The definition of what constitutes a functional failure is of primary importance. Whenever a functional failure is defined by some level of performance, condition, or dimension, the appropriate standard must be stated to provide the basis for establishing whether a functional failure has occurred.

6.9 Phase 3: Additional Functionally Significant Item Selection (OPNAV FORM 4790/117, Appendix B-3)

All systems and subsystems listed in the Master Systems and Subsystems Index are considered Functionally Significant Items (FSIs) and are subject to further analysis. The Additional FSI (AFSI) Selection form identifies functions as well as functional failure information for lower levels of indenture, as required. This form can be used as a tool to aid the developer in deciding if lower level analysis is needed.

If any of the functions listed on the AFSI Selection form are necessary for safety, mobility, or mission, or if any of the functional failures impact safety, happen frequently, or are expensive to repair, the analyst transfers the AFSI candidate to the FSI Index. MIL-P-24534A, paragraph 3.7.4.3, provides detailed guidance for performing this task.

Remember, the use of the Additional FSI Selection form is required only if the analyst considers it necessary to analyze individual items at the equipment level or below.

When the analyst has completed this phase of the development process, he should have one of the following:

- A single FSI for the entire system
- FSIs for the system and each subsystem
- FSIs for the system and each subsystem and for some items at lower indenture levels.

MIL-P-24534A, paragraph 3.7.4.5, provides detailed guidance for performing this task.

6.10 Phase 3 Continued: Functionally Significant Items Index (OPNAV FORM 4790/118, Appendix B-4)

The FSI Index simply lists, in SWAB hierarchical order, all of the FSIs, system by system. It summarizes all of the work done to identify FSIs. Analysts will prepare a Failure Modes and Effects Analysis for every item on this index.

6.11 Phase 4: Failure Modes And Effects Analysis (OPNAV FORM 4790/119, Appendix B-5)

The Failure Modes and Effects Analysis (FMEA) provides the basic failure information required for applying the RCM decision logic analysis. The FMEA identifies the specific conditions that are the dominant causes for functional failures. These are the conditions that a PM task is intended to prevent or discover.

The FMEA is intended to identify dominant failure modes, those whose impact, either as individual or frequent events, requires consideration for preventive maintenance tasks. A functional failure is an unsatisfactory condition (i.e., an intended function is not adequately provided). A failure mode is a specific condition causing a functional failure, including such modes as a leaking seal, broken shaft, or seized bearing. A dominant failure mode is one that happens relatively often or that has very serious consequences. It is important to recognize the difference between the functional failure (e.g., lube oil temperature exceeds normal range) and the failure mode (wiped bearing).

The quality of the FMEA is the key to the quality of the resulting preventive maintenance program. This step in the development process requires a realistic, rather than academic, evaluation of failures. The analyst should identify the dominant failure modes, not hypothetical modes that do not or are not likely to happen. Some functional failures may have no dominant failure modes. Active participation of shipboard operator/maintainers in this analysis can have a major beneficial impact.

The effects of failure are then evaluated at three levels:

- Locally (i.e., at the site of the failure mode)
- At the subsystem level (i.e., effects within the partition boundary)

- At the system level, including the system outputs and the end effect, outside the partition boundary (i.e., effects on the ship or its mission)

The consequences of failure are a factor in determining how worthwhile it is to attempt to prevent that failure mode. That is, failure effects -- in terms of risk – have a direct bearing on the effectiveness (value added) of a proposed maintenance task.

Each FSI in the FSI Index requires an FMEA. Efficient FMEA preparation analyzes the lowest level FSIs first, followed by the associated subsystem and system level FSIs. Identify failure modes within the lowest FSI level at which they can be perceived. For example, a pump might be the lowest level of indenture and the failure mode might be an eroded impeller. Do not repeat these at higher indenture levels.

If a failure mode is found to have insignificant effects, or is only remotely likely to occur, the analyst should not consider it for logic tree analysis but should provide rationale for this decision on FMEA backup sheets. MIL-P-24534A, paragraph 3.7.5, provides detailed guidance for performing this task.

6.12 Phase 5: Decision Logic Tree Analysis (OPNAV Form 4790/120, Appendix B-6)

The RCM process for identifying applicable and effective tasks uses a decision logic tree. The RCM decision logic tree uses a series of yes/no questions about a functional failure and its associated failure modes that help to determine the need for and availability of applicable and effective preventive maintenance tasks. The answers to these questions will ultimately tell us about this failure's criticality (which may be different for each failure mode) and whether or not there is an applicable *and* effective maintenance task that will avoid it. The first three questions in the Decision Logic Tree (shown in Figure 6-2) determine failure classification, while the remaining questions deal with the search for applicable and effective tasks or with changing the design of the hardware.

Applying this logic will identify what, if any, preventive maintenance tasks should be performed. Loss of safety-critical on-line functions or the expectation of safety-critical failures requires either a preventive maintenance task or specific acceptance of the identified risks. Loss of on-line functions that are not safety-critical leads to trade-offs that determine task desirability, depending on mission criticality. On-line failures directly affecting mission are considered separately from those of support functions because of their higher level of impact.

Off-line functions are considered separately. There are classes of off-line functions:

- Hidden functions that protect the ship from multiple failures; and
- Mission functions that are not used often enough to provide confidence that they will be available when required.

Either preventive tasks or failure-finding tasks may be required to ensure acceptable availability of off-line functions when required.

Functional failures or failure modes with unacceptable risk or for which there are no applicable and effective preventive maintenance tasks should be considered for design changes that either:

- Reduce the probability or severity of failure; or
- Enable development of an applicable and effective preventive maintenance task

The quality of the results from applying the decision logic depends considerably on the understanding of each question in the tree. Therefore, we will consider each question in some detail. Detailed instructions for filling out the associated form are provided in MIL-P-24534A paragraph 3.7.6.5

Question 1. *Is the occurrence of a failure evident to the operating crew while it is performing its normal duties?* This question divides functional failures into two groups: evident and hidden.

- **YES.** Those that reveal themselves to the crew during their normal day-to-day activities; evident or on-line functions. The analyst must know exactly how this can occur. Go to Question 2.

- **NO.** Those that are discovered when operation of infrequently used equipment is attempted or when protective or back-up systems fail to operate when needed; hidden or off-line functions. Go to Question 7.

*Note: The analyst must provide justification for either a Yes or a No answer, explaining either how and to whom the failure is made evident or why it is hidden from the crew during normal operations.

Question 2. *Does the failure cause a loss of function or secondary damage that has a direct and adverse effect on operating safety?*

- **YES.** Those that directly impact operating safety. Where safety relates to threats to life and limb of the crew or others, not to equipment damage that does not threaten people. It involves direct, major threats and not improbable combinations of events that have minor impact or are unlikely. {If developing an initial program for a new ship class, the analysts must determine the impact of failure by reviewing drawings and specifications and through the application of experience -- theirs and that of operator/maintainers – with similar systems. If there is considerable in-service experience, the analyst should examine it to see whether or not safety has, in fact, been affected by this particular failure.} Go to Question 4.

- **NO.** Those that do not impact operating safety as described above. Go to Question 3.

*Note: The analyst must provide justification for a Yes answer. The justification must address the threat to life, limb, or health of the crew.

Question 3. *Does the failure have a direct and adverse effect on operational capability?* This question divides the non-safety-related on-line failures into two groups: Mission impact and support function impact

- **YES.** Those that directly impact operational capability (mission). These failures affect the ability of the ship to perform its function as a ship, including any military functions in regular, frequent use. Go to Question 5.

- **NO.** Those that impact only support functions. Go to Question 6.

*Note: The analyst must provide justification for a Yes answer. The justification must address the reduction or loss of mission capability.

Questions 4,5,6,7. *Is there an effective and applicable preventive maintenance task or combination of tasks that will prevent functional failures?*

Questions 4,5,6,7 are essentially the same, but the rules for evaluating effectiveness of an applicable task are different for the three evident classes of failure:

- Class A: Safety-related or Regulatory
- Class B: Mission-related
- Class C: Other Support Functions

Furthermore, the rules for determining applicability of a proposed task are different for the two types of task considered in this phase:

- Condition-directed
- Time-directed

The analyst should not limit the answer by consideration of the maintenance level at which these tasks will be done. This question applies to all functional failures regardless of the repair level and separates them into two groups:

- **NO.** Those for which there is no effective and applicable task

- **YES.** Those for which an applicable and effective preventive maintenance task (or tasks) can be specified.

Answering Questions 4,5,6,7 requires more effort than answering Questions 1,2,3. A practical way of doing so is to:

a. Propose a task
b. Classify the task as condition-directed or time-directed
c. Test the task for applicability using the appropriate rule (CD or TD) reiterated below
d. Determine the failure consequences
e. Test the task for effectiveness by using the rule appropriate to Question 4 (Safety and Environmental), 5 (Mission) or 6 (All Others). The appropriate effectiveness rule for Question 7 (Hidden failure) depends on the consequences of the secondary failure the hidden function is intended to prevent.

An applicable task is one that actually prevents, discovers, or reduces the impact of the failure mode in question. The rules for testing applicability depend on the type of task: Condition-Directed, or Time-Directed.

Each task candidate for questions 4,5,6,7 will be either a time-directed task (TD), or a condition-directed task (CD). Only question 8 deals with failure finding (FF) tasks.

- Time-directed tasks can be applicable only if the item exhibits an increased risk of failure after some age has been reached and if there is no condition that predicts failure.

- Condition-directed tasks can be applicable only if occurrence of a specific failure mode is preceded by a reduction in resistance to failure that is detectable sufficiently in advance of actual failure so that appropriate action can be taken to avoid the actual failure.

The rule of effectiveness varies with the consequences of failure.

- Class A. For safety-related failures and for failures related to regulatory requirements, the risk of failure must be reduced to a very low level. Since the severity of a safety-related failure is considered to be very high, this equates to reducing *the probability of failure* (P_f) to an acceptable level despite the cost. (This does not mean that cost should not be considered. For example, a design change may reduce the probability of failure at a lower life cycle cost than the use of resource intensive maintenance tasks.)

- Class B. For mission-related failures, effective means that the value of the resulting increase in reliability clearly exceeds the total cost of the task. In other words, *the risk of failure* ($P_f \times S_f$) must be reduced to an acceptable level.

- Class C. For all other evident failures, the cost of performing the maintenance must be less than the direct costs of the failure it is designed to prevent, that is, cost of repair plus the cost of lost capability.

- Class D. For hidden failures, the rule for effectiveness is determined by the consequences of the secondary failure that the hidden function is intended to prevent. E.g., the consequences of overpressure of a propulsion boiler or overpressure of an air conditioning chill water expansion tank due to a stuck relief valve are quite different.

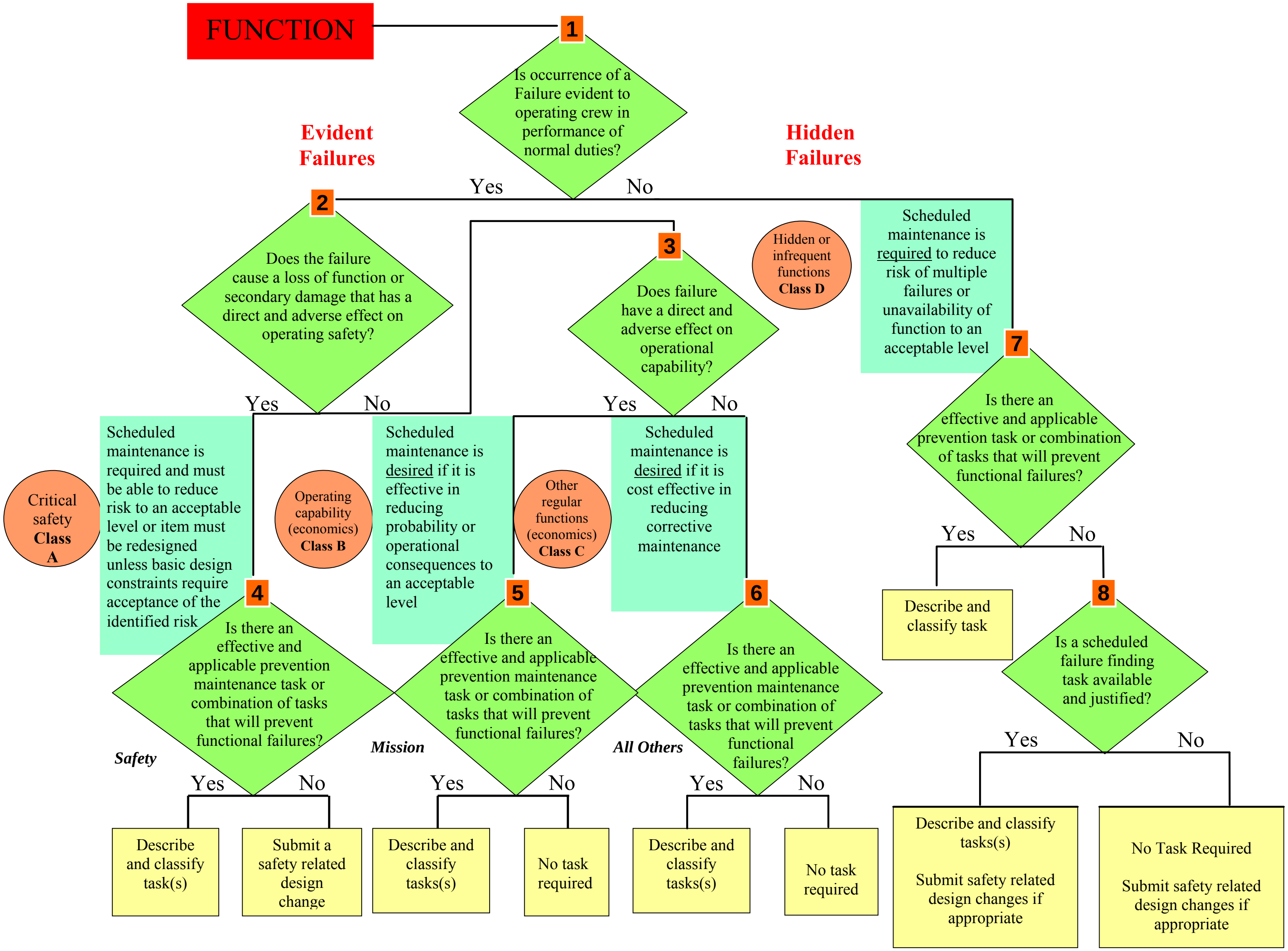
Question 8. *Is a scheduled failure finding task available and justified?*

- **YES.** Those for which an applicable and effective preventive maintenance task (or tasks) can be specified.

- Failure finding tasks are applicable only if they find a failure that is not evident to the operating crew during routine operations.

- Class D. For hidden failures, the rule for effectiveness is determined by the consequences of the secondary failure that the hidden function is intended to prevent.

➢ **NO.** Those for which there is no task to be developed. Consider the need for a safety-related design change.



RCM Decision Logic Tree
(Figure 6-2)

6.13 Phase 6: Servicing and Lubrication Analysis (OPNAV Form 4790/121, Appendix B-7)

Servicing consists of the routine replenishment of bulk consumables other than lubricants. These include hydraulic fluid, coolants, etc. These tasks could be established by using the RCM logic; however, a separate analysis of servicing and lubrication requirements is performed to ensure that these routine tasks are not overlooked. MIL-P-24534A paragraph 3.7.7 provides direction for accomplishing this simplified analysis.

The analysis is based on review of existing requirements:

- PMS for existing ships; or
- Manufacturers' recommendations for new ships and equipment

6.14 Periodicity Considerations

No practical methods have been developed for determining the correct periodicity of preventive maintenance tasks. Even knowing the in-service statistical age-reliability characteristics of the system or equipment affected by the desired task may not yield a satisfactory answer given the random nature of most failures

If the analyst concludes that a periodic preventive maintenance task is necessary, it is unlikely that, from the available information, he or she can select the best periodicity at the first try. Neither the failure rate nor its inverse, the Mean Time Between Failure (MTBF), is a proper basis for periodicity selection because it does not give any information about the effect of increasing age on reliability. It only gives the average age at which failure occurs. Effectiveness of the initial periodicity selection can be evaluated using the techniques of Backfit RCM (Section 8) as operating experience is gained.

6.15 Phase 7: Audit and Preparation of the Maintenance Requirement: Maintenance Requirement Index (MRI)(OPNAV Form 4790/123, Appendix B-8)

Once the required maintenance actions have been determined by use of logic tree analysis and of servicing and lubrication analysis, the results are gathered in one place, grouped by system or subsystem, and audited for completeness. The MRI lists all tasks identified with recommended periodicity. The analyst also includes reference to existing Maintenance Requirement Cards (MRCs) that satisfy the requirement or that can be modified to suit it, and notes those tasks for which no suitable MRCs or combination of MRCs exist. MIL-P-24534A paragraph 3.7.9 provides detailed instructions for this phase.

6.16 Phase 8: Method Study and Procedure Evaluation for New Tasks and Revised Maintenance Requirement Cards (MRCs)(OPNAV Form 4690/130, Appendix B-9)

The analyst develops each task, using the Procedure Evaluation Sheet, as described in MIL-P-24534A paragraphs 3.7.10 and 3.10. The object is to determine the most practical method of accomplishing the task. The method chosen should be the best engineering solution consistent with resources available.

The procedure evaluation serves to identify any hazards, eliminating each, if possible, and to ensure that only necessary actions are incorporated in the procedure.

6.17 Phase 9: Maintenance Requirement Task Definition (OPNAV Form 4790/124, Appendix B-10)

Following approval of Phase 8, the analyst collects sufficient data to enable a decision as to what maintenance level (organization, intermediate, or depot) should be assigned for task accomplishment as well as to write the maintenance procedure. Detailed instructions are provided in MIL-P-24534A, paragraph 3.7.11. The completed form includes safety precautions, information concerning the personnel requirements, accomplishment manhours (less make ready and put away), required materials, and maintenance level.

6.18 Phase 10: Inactive Equipment Maintenance (OPNAV Form 4790/129, Appendix B-11)

Inactive Equipment Maintenance (IEM) is invoked during extended periods of inactivity of the system/equipment or when it is subject to an industrial environment such as during a depot level availability. Examples include protecting equipment from industrial debris and providing dehumidification or inert gas protection for moisture-sensitive systems and equipment, such as propulsion reduction gears and radar waveguides.

The purpose of IEM is to:

- Prepare equipment for extended periods of inactivity -- Lay-up procedures (LU)
- Prevent deterioration during the inactive period -- Periodic Maintenance (PM)
- Prepare the equipment for operation again -- Start Up procedures (SU)
- Ensure proper operation once reactivated – Operational Tests (OT)

Note that equipment level SU and OT procedures must be accomplished before system level SU and OT procedures.

The IEM development process provides a method to:

- Determine the maintenance actions required
- Identify the source of the required actions
- Identify and develop required procedures not available
- Assign the maintenance tasks to the appropriate maintenance level

Note that IEM analysis assumes the equipment was operational when inactivated.

Detailed instructions are provided in MIL-P-24534A, paragraphs 3.7.12 and 3.10.

6.19 Phase 11: Unscheduled Maintenance

Unscheduled Maintenance (UM) requirements are those documented actions required to return systems or equipment to an operational condition within predetermined tolerances or limitations. Tasks include such corrective maintenance actions as alignment, adjustment, replacement and repair procedures. Testing and other actions such as 'open and inspect' that are not required as scheduled maintenance may be included as UM.

Unscheduled Maintenance requirements are discussed briefly in MIL-P-24534A paragraphs 3.7.13 and 3.9.

6.20 Phase 12: MRC/MIP Preparation (OPNAV Form 4790/85, Appendix B-12, B-13)

Following approval of PMS task recommendations, the PMS Coordinating Activity will direct development of the draft MIPs and MRCs for verification. Details for preparation of MIPs and MRCs are provided in MIL-P-24534A paragraphs 3.11 and 3.12. Further discussion of these administrative details of final preparation, approval, and distribution is not required in this handbook.

6.21 eRCM

eRCM is a web-based RCM analysis application that resides on Navy servers. The application facilitates the paperless implementation of MIL-P-24534A for the determination of maintenance requirements and for the development of associated Maintenance Requirements Cards, Maintenance Index Pages, and associated RCM analysis documentation.

eRCM automates the MIL-P-24534A RCM analysis steps. That is, one portion of the application automates Phases 1 through 7 of the MIL-P process. The analyst must continue to apply maintenance engineering and operational expertise and experience to his or her decisions. The eRCM application is merely an efficient tool that simplifies the administrative workload and serves to focus the analyst's attention.

The eRCM application is to support Phases 8-12 of the MIL-P-24534A process and a paperless transition of the RCM analysis of phases 1 through 7 into actual MRCs and MIPs.

The application walks the analyst through the logic of each of the first seven MIL-P-24534A phases, beginning with the requirement to provide functional block diagram and partitioning and ending with automatic preparation of the Maintenance Requirement Index. Although the application does not provide tools for actually constructing functional block diagrams, it does provide options for submitting them; either by attaching softcopies or notifying the PMS Coordinating Activity that block diagrams are being provided by other means such as email or postal mail.

In Phases 2 through 7, the application steps the analyst through the logic specified in MIL-P-24534A. In addition, the software provides help and aids to facilitate analyst recall of the understanding gained in the RCM Level II certification course. The application also uses prior data entries to select appropriate screens and to pre-load screen fields as the user progresses through the logic. For example, if the analyst defines the task to be a time-directed task, the application provides subsequent screens related only to time-directed tasks.

As required by MIL-P-24534A, each data package must be reviewed and approved by the PMS Coordinating Activity, which currently resides at NAVSEALOGCEN. When all phases are completed for a data submission package, the application notifies the appropriate commodity specialist at the PMS Coordinating Activity that the package is ready for review. The application does not allow the analyst to proceed with the phases included in the next data package until the preceding package has been approved. The application notifies the submitting analyst by email when the commodity specialist completes the review and approves or rejects the package. Ongoing communication between analyst and commodity specialist is essential throughout the project to resolve misunderstanding and differences of opinion.

6.22 Summary

The "Classic" RCM process as laid out in Mil-P-24534A (Navy) guides the maintenance developer through the thought process for designing a preventive maintenance program for systems and equipment. The process consists of 12 phases:

- Phase 1 – Functional Block Diagram and the Master Systems and Subsystem Index
- Phase 2 – Functional Failure Analysis
- Phase 3 – Additional Functionally Significant Item (FSI) Selection and FSI Index
- Phase 4 – Failure Modes and Effects Analysis (FMEA)
- Phase 5 – Decision Logic Tree Analysis
- Phase 6 – Servicing and Lubrication Analysis
- Phase 7 – Audit and Preparation of the Maintenance Requirements Index
- Phase 8 – Method Study and Procedural Evaluation for New Tasks and Revised Maintenance Requirements Cards (MRC)
- Phase 9 – Maintenance Requirements Task Definition
- Phase 10 – Inactive Equipment Maintenance
- Phase 11 – Unscheduled Maintenance
- Phase 12 – MRC/MIP Preparation

Each phase is designed to make the developer consider and answer important questions outlined in the RCM process. The tasks and procedures developed are the best that can be written with the resources and knowledge available.

In phases 1 – 3 the developer gathers detailed knowledge about the system and its functions so he can make good decisions about what failures will be of most concern in the intended system application.

In phases 4 – 7 the developer considers all the failure modes that could result in loss of system function, and determines which failure modes are the greatest risk. These dominant failure modes are then analyzed in the decision logic tree to determine the best course of action to manage the associated risk. These steps are the most critical part of the RCM process.

In phases 8 – 12 the task descriptions resulting from the application of RCM decision logic are combined into accurate detailed procedures for accomplishment. Careful consideration is given to manpower, materials and training required and logical sequencing of steps to obtain the best procedure possible and determining the appropriate maintenance level for accomplishing the procedure.

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Section 7—The Backfit RCM Process

This section describes the steps taken and the forms used to validate the adequacy of existing maintenance programs for systems, subsystems and equipment for which there is a significant body of operational and maintenance history.

The objective of applying Backfit RCM to a system and its subsystems and equipment is to establish

- The right maintenance
- On the right systems and equipment
- At the right interval

7.1 Analyst Selection and Training

Although Naval Sea Systems Command is the technical authority for Planned Maintenance task determination, continuous improvement of RCM-based maintenance is best accomplished by applying the same three skills used for the original development of the maintenance program.

- An understanding of the system's design from the viewpoint of the designer, typically embodied in the responsible Navy in-service engineer (ISE) who exercises technical authority for the system(s) involved;
- An in depth understanding of how the system is used and of its actual dominant failures and acceptable operating characteristics, typically embodied in a Navy ship's work center supervisor operator and maintainer;
- An understanding of in-service reliability analysis and preparation of maintenance requirements documents embodied in the responsible Navy commodity specialist who performs final review of any PMS package modifications for publication.

The most effective RCM applications result when persons having these skills work together. An effective way to achieve this objective is to bring ISEs and shipboard operators and maintainers for similar systems together for a concentrated session of training, analysis, and recommendation of changes. A PMS commodity specialist who works with several ISEs provides the third skill.

Those preparing, reviewing, or approving scheduled maintenance requirements require training and NAVSEA certification in RCM concepts and methodology and in use of the documentation specified in MIL-P-24534A. All Navy and contractor personnel involved with development, review, or approval of PMS tasks must successfully complete training and achieve RCM Level I certification through the NAVSEA RCM Certification Program administered by SEA 04 and as mandated in the NAVSEAINST 4790.8 (series) Ships' Maintenance and Material Management (3-M) Manual to make changes to existing PMS maintenance requirements.

7.2 Information Collection

The analyst should gather necessary technical information for each ship system to be analyzed and its equipment for each ship class.

- Existing Maintenance Index Pages (MIP) and Maintenance Requirement Cards (MRC) for the system(s) to be reviewed
- Original Classic RCM analysis forms
- 3M System failure data
- Technical manuals or other technical data, as needed.

Acquisition and distribution of this information may be handled as a specific assignment under the direction of the activity managing the review. For Backfit RCM analysis conducted under the Ship Maintenance Effectiveness Review (SHIPMER) process, NAVSEA 04 collects all applicable MIPs/MRCs, while the ISEs may provide 3M data and any other relevant information particular to their assigned systems.

7.3 The Backfit RCM Methodology

The Classic RCM methodology described in Section 6 is used to develop applicable and effective maintenance tasks for new systems, subsystems, and equipment during ship acquisition and as the ship class is modernized during its service life. Initial task development is only the first step in developing a good maintenance program, however. The final step of Classic RCM is one of continuous improvement. That is where Backfit RCM takes over.

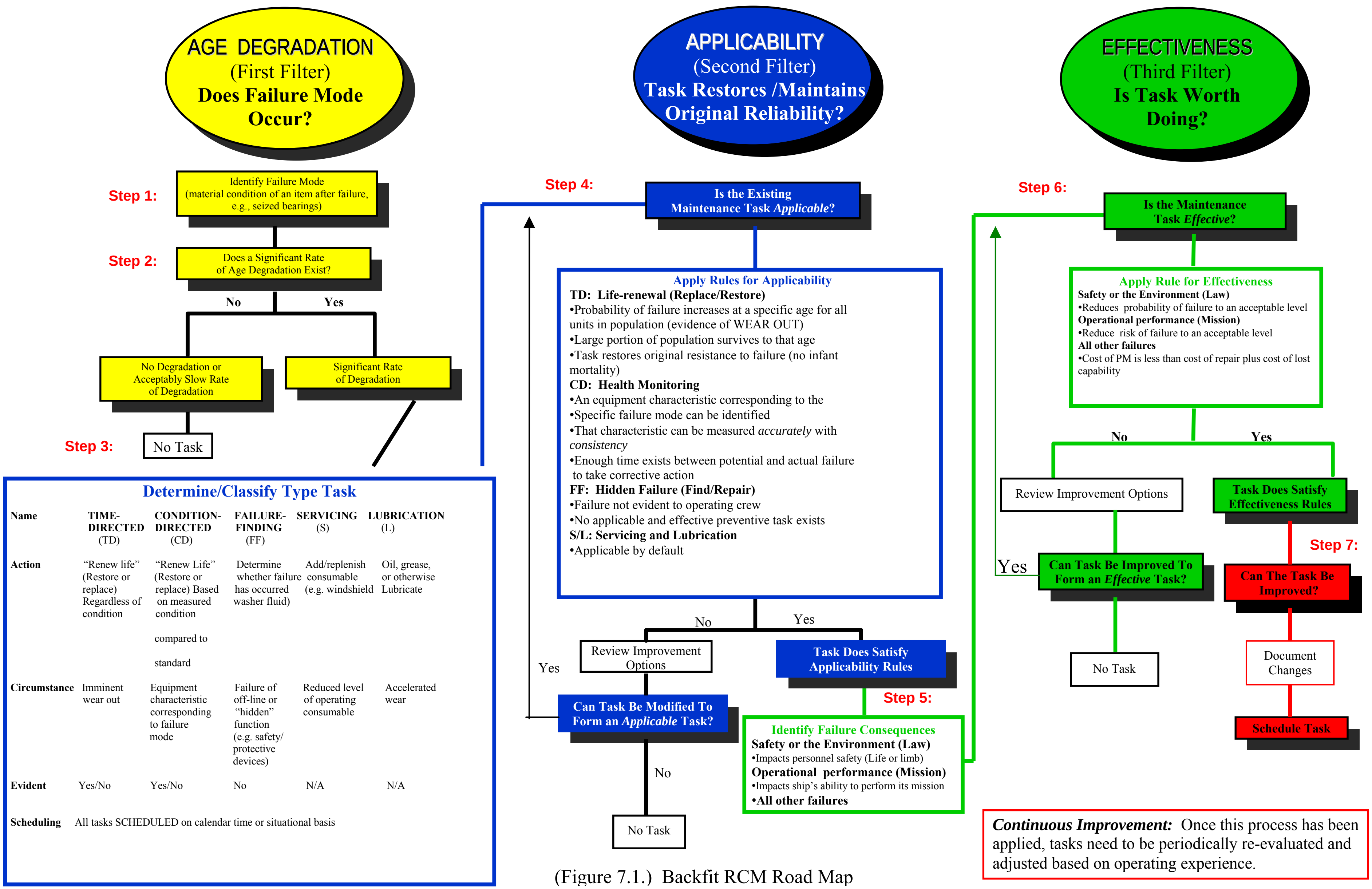
No maintenance program should remain static. Successful maintenance programs build on operational experience in a program of continuous improvement that leads toward an optimized set of maintenance tasks over time.

Backfit RCM is a methodology developed to validate existing maintenance requirements by using basic maintenance concepts explained in Sections 2 through 4 and by applying operational experience. The methodology first looks to see if the system does really experience age degradation; i.e., the assumed failure modes do, in fact, occur. If there is a history of age degradation, the current tasks are analyzed for applicability and effectiveness. If the assumed failure modes do not occur, then the existing PMS tasks serve no useful purpose and can be eliminated.

7.4 Conducting a Backfit RCM Analysis of an Existing PMS Program

The Backfit RCM methodology uses a decision tree or road map (Figure 7.1) with steps in the areas of Reliability Degradation, Task Applicability, Task Effectiveness, and Recommending Change. The six steps are applied in a manner similar to that described in Section 6 for Classic RCM. The process validates existing maintenance requirements using basic maintenance concepts and operational experience.

Road Map for "Backfit" RCM



Determine/Classify Type Task

Name	TIME-DIRECTED (TD)	CONDITION-DIRECTED (CD)	FAILURE-FINDING (FF)	SERVICING (S)	LUBRICATION (L)
Action	"Renew life" (Restore or replace) Regardless of condition	"Renew Life" (Restore or replace) Based on measured condition compared to standard	Determine whether failure has occurred	Add/replenish consumable (e.g. windshield washer fluid)	Oil, grease, or otherwise Lubricate
Circumstance	Imminent wear out	Equipment characteristic corresponding to failure mode	Failure of off-line or "hidden" function (e.g. safety/ protective devices)	Reduced level of operating consumable	Accelerated wear
Evident	Yes/No	Yes/No	No	N/A	N/A
Scheduling	All tasks SCHEDULED on calendar time or situational basis				

(Figure 7.1.) Backfit RCM Road Map

The quality of the results from applying the decision logic depends considerably on the understanding of each step. Therefore, we will consider each step in some detail.

Step 1. *Identify Failure Mode*: Identify the Functional Failure and Failure Mode that the existing task is intended to prevent. Each maintenance task is designed to prevent (condition-directed, time-directed, servicing and lubrication tasks) or to identify (failure finding tasks) a failure mode.

For each maintenance task, the analyst identifies the functional failure and failure mode that the task is intended to prevent and enters it in Block 1 of the Backfit Data Entry Form. Classic RCM identified probable failures and failure modes. Backfit RCM analysis uses operational experience to address the failure modes that each maintenance task was designed to prevent. Remember that failure modes are causes of functional failures, while functional failures can be viewed as the effect of what happens to a system or equipment. The failure mode is the material condition after failure. Preventive maintenance tasks are intended to prevent specific failure modes that result in functional failure.

Using 3M data and other operational information, the analysts determine whether or not the failure mode actually occurs.

Step 2. *Does a significant rate of age degradation exist? Does the Failure Mode actually occur in service life?*

Based upon your operational and professional experience, does this failure mode actually occur within the service life of the equipment?

- **YES.** If the failure mode does occur or if the analyst is unsure, mark the "Yes" block and move to the next step.

- **NO.** If the item does not degrade meaningfully with age or if the degradation is sufficiently slow as to be of no practical concern, then there is no need for the task, and it can be deleted. Mark "No" in Block 2 and check "Delete Task" in the Change Recommendations section of the Feedback Form. The analysis is then complete.

Determination of the significance of the degradation, if any, is based upon safety, mission impact, or financial considerations.

Step 3. *Determine and Classify The Type Of Maintenance Task.*

As explained in Section 4.5, there are five types of preventive maintenance tasks:

- Condition-Directed tasks renew life based on objective, observable evidence of need (i.e., based on a measured condition compared with a standard).
- Time-directed tasks renew life based on statistical analysis of population wear out regardless of actual condition.
- Failure Finding tasks determine whether or not a hidden functional failure has occurred.

- Servicing tasks add or replenish materials consumed as part of, and necessary for, the functionality of the equipment or system (i.e., paper in a computer printer, toner in a copy machine, or fuel in an engine).
- Lubrication tasks oil, grease, or otherwise lubricate machinery.

Mark the type of task in Block 3. Determination of the type of maintenance task is important because the rules that are applied to evaluate task applicability differ depending on task type.

Remember that all tasks are scheduled, not just those few that are time-directed life-renewal maintenance tasks; and, scheduling of the task has no bearing on the task type classification.

Step 4. *Is The Existing Maintenance Task Applicable (Relevant)?*

An "applicable" task is one that restores or maintains the inherent equipment, system, or component reliability. The task is determined to be "applicable" if it satisfies all of the rules for its task type. Remember that each type of task has its own specific rules for applicability.

- Condition-Directed. Condition-directed tasks are applicable only if an equipment characteristic corresponding to the specific failure mode can be identified, and the potential failure can be measured accurately with consistency, and enough time exists between potential and actual failure to take corrective action.

- Time-Directed. Time-directed tasks are applicable only if the item exhibits an increased probability of failure at some age, and a large portion of the population survives to that age, and a potential failure point does not exist or cannot be measured.

- Failure Finding. Failure-finding tasks are applicable only if they find a failure that is not evident to the operating crew during routine operations and a potential failure point does not exist or cannot be measured

- Servicing and Lubrication tasks are assumed applicable by their very nature. Mark Block 4 "N/A."

➢ **YES.** If the classified task satisfies all of the appropriate rules for applicability, the analyst marks "Yes" in Block 4 and provides a rationale for how each applicability rule is satisfied, or how the maintenance requirement (MR) was modified to make it applicable.

➢ **NO.** If the task, as written, does not satisfy all of the applicability rules for that type of task, mark "No" in Block 4 and evaluate whether the maintenance task can be modified to establish an Applicable task. If so, list recommended improvements to change the task so it will satisfy the Applicability Rule. The analyst has several options to consider, including:

- Change task type (i.e., Time-Directed to Condition-Directed);
- Modify the procedure or the scope of task procedures; and
- Change measurement of age (i.e., operating hours vs. start/stops).

If a task is modified to replace the non-applicable task, it must then be tested on its own and pass the Rules of Applicability for the modified task. If a task cannot be modified to satisfy the applicability criteria, explain why not, delete the task, and mark the appropriate box in the Task Improvement (or "Change Recommendations") section.

Step 5. *Identify Failure Consequences.*

Determine whether the consequence of the failure being evaluated has a detrimental impact on safety of personnel, violates federal or state laws, or impacts the ability of the ship to perform its mission. In Block 5 of the Backfit RCM Form, mark "Safety/Law" for the first impact situation, "Mission" for mission impact, or "All Others" for all other failures.

Step 6. *Is the Maintenance Task Effective?*

Using the Road Map for "Backfit" RCM, apply the Rule of Effectiveness for the Failure Consequence identified in Step #5:

- For failures involving personnel safety (life or limb) or law (e.g., environmental regulations), a task is effective if and only if it reduces the probability of failure to an acceptable level.
- For failures involving operational performance (i.e., ship's mission), a task is effective if it reduces the risk of failure (P_f x S_f) to an acceptable level.
- For all other failures, a task is effective if the cost of the preventive maintenance is less than the cost of repair plus the cost of lost capability.

➢ **YES.** If the Rule for Effectiveness is satisfied, mark "YES" and explain how the task satisfies the Rule.

➢ **NO.** If the rule is not satisfied, mark "NO", review the Road Map for "Backfit" RCM for improvement options, and evaluate whether the maintenance task can be modified to establish an Effective task. If so, list recommended improvements to change the task so it will satisfy the Effectiveness Rule.

The analyst has several options to consider including:

- Extend task periodicity;
- Sample vs. 100% inspection;
- Make task situational vice calendar-based scheduling; and
- Modify task procedures.

If a task is modified to replace the non-effective task, it must then be tested on its own and pass the Rule of Effectiveness for the modified task. If a task cannot be modified to satisfy the effectiveness criteria, explain why not, delete the task, and mark the appropriate box in the Task Improvement (or "Change Recommendations") section.

Step 7. *Can the Task be Improved?*

Even though a task may be applicable and effective, it may still be a candidate for improvement. For example, its effectiveness can possibly be increased by ***age exploration***.

Age-exploration is the systematic process of increasing the time between preventive maintenance actions and monitoring results to achieve the optimal periodicity. The risk of failure is factored into the age-exploration process. For example, we may have a maintenance task to inspect and clean an air filter that is performed weekly. However, the Sailor finds that he very rarely finds the filter dirty enough to require cleaning. We can then age-explore the periodicity of the inspection to monthly or quarterly. Based upon as-found condition, we should increase the periodicity of the maintenance as far as risk will allow. When we have incrementally increased the periodicity to the point where we are seeing failures prior to the preventive maintenance interval, we then decrease the periodicity to the last successful interval to get back inside the failure point. Age-exploration is a very effective means to achieve the most cost-effective maintenance possible.

Other recommended changes range from deletion of tasks when there is no evidence of degradation to modification of tasks that fail the applicability test or whose effectiveness might be improved. Mark the appropriate choice in the Change Recommendations section:

- Delete task
- Modify task
- Add new task
- Change measurement of age
- Change task periodicity, i.e., conduct age exploration (Insert recommended periodicity.)
- Combine with another MIP and MRC
- Delete MIP
- Other
- No change

The analyst must describe any recommended changes in sufficient detail to support development of a new or modified MIP and MRC. Rationale must be provided for any recommended changes as well as for no change

7.5 Finalizing PMS Task Revisions

The ISE analyst submits the completed Backfit RCM Data Entry Form(s) to the cognizant commodity specialist via NAVSEA 04RM. Submittal of the form constitutes the ISEs technical authority approval of the documented changes. The commodity specialist prepares necessary MIP and MRC in accordance with MIL-P-24534A paragraphs 3.11 and 3.12 using the approved PMS editing software. Further discussion of the administrative details of final preparation, approval and distribution is not required in this handbook.

7. 6 Summary

The "Backfit" RCM methodology provides a means of implementing continuous improvement in the maintenance program. Using experience gained through operation, maintenance, and monitoring of the equipment, existing maintenance procedures are reviewed to determine:

1. Are the failure modes being addressed by the maintenance procedure those that really occur in service and impact the required functionality of the system.
2. Is the task implemented in the procedure for addressing the failure mode 'applicable' in preventing the failure or are improvements required/desired.
3. Is the task an 'effective' expenditure of resources in relation to the consequences of the failure or are improvements required/desired.

In addition, a detailed look at the procedure steps is performed to effect any improvements in process or technique and to validate the requirements for manpower and materials (especially hazardous materials). The scheduling of each task is also reviewed to determine if any changes are required or if the task might be a good candidate for age exploration.

Appendix A—GLOSSARY

Active Function	A function requiring some specific action of a hardware element
Age Degradation	A reduction of the item's operating reliability caused by reduction of the item's resistance to failure as it is used
Alterative Maintenance	To eliminate a specific unsatisfactory condition by altering the design of an item
Applicable Task	A task that prevents, discovers, or reduces the impact of the failure mode in question
Condition-Directed Task	A periodic diagnostic test or inspection that compares the existing material condition or performance of an item with established standards and takes further action accordingly
Corrective Maintenance	To restore lost or degraded functions by correcting unsatisfactory conditions
Dominant Failure Modes	Failure modes that either occur frequently or have serious consequences or both
Effective Task	A task that provides value and, therefore, may be worth doing. The determination of whether a task is effective requires examining the failure consequences
Failure	The presence of an unsatisfactory condition
Failure Effect	Consequences of a failure mode
Failure-Finding Task	A task used to evaluate the condition of functions whose failures would be hidden from the operating crew
Failure Mode	The specific condition causing a functional failure (often best described by the condition after failure)
Function	Any action or operation, which an item is intended to perform
Functional Failure	An unsatisfactory condition in which intended functions are not adequately provided
Hidden Function	A function that is not observable by the crew during normal operations. It is provided by an item for which there is no immediate indication of malfunction or failure; e.g., failure of a relief valve to lift
Inherent Reliability	The level of reliability of an item or of equipment that is attainable with an effective scheduled maintenance program
Off-Line Function	A function not continuously or continually provided that is activated by some action or event
On-Line Function	A function continuously or continually provided during normal operation.
Passive Function	A function provided without specific action of a hardware element (e.g., containment, insulation, etc.)
Potential Failure	An identifiable physical condition which indicates a functional failure is imminent
Preventative Maintenance	To minimize conditions that cause unacceptable degradation of functions

RCM	Reliability-Centered Maintenance. A methodology to develop or revise a maintenance approach with the objective of maintaining the inherent reliability of the system or equipment, recognizing that changes in inherent reliability may be achieved only through design changes
Redundancy	System capacity in excess of requirements that avoids loss of function as the result of item failure
Risk	A function of both the probability of failure and the severity of the failure consequences
Safety	Protection from threats to life or limb
Time-Directed task	A task that restores or replaces an item regardless of its actual material condition before the item reaches an age at which the probability of failure becomes much greater than at earlier ages

Appendix B—MIL-P-24534A (NAVY) Data Forms

1. SWAB GROUP NUMBER	2. NOMENCLATURE		3. SHIP CLASS	SH OF
4. PREPARED BY DATE	5. REVIEWED BY DATE	6. APPROVED BY DATE	7. REVISION DATE	
8. SWAB SUBGROUP/SYSTEM/ SUBSYSTEM NUMBER	9. SUBGROUP/SYSTEM/SUBSYSTEM NOMENCLATURE			
			10. SERIAL NUMBER	

MASTER SYSTEMS AND SUBSYSTEMS INDEX
OPNAV 4790/114 (ED 2-82)

Master Systems and Subsystems Index (OPNAV FORM 4790/114)

<table>
<tr><td>1. SWAB NUMBER</td><td colspan="2">2. NOMENCLATURE</td><td>3. SHIP CLASS</td><td>SH
OF</td></tr>
<tr><td>4. PREPARED BY
DATE</td><td>5. REVIEWED BY
DATE</td><td>6. APPROVED BY
DATE</td><td>7. REVISION
DATE</td><td></td></tr>
<tr><td colspan="5">8. SOURCES OF INFORMATION</td></tr>
<tr><td colspan="5">9. DESCRIPTION (Add additional sheet, if necessary)</td></tr>
<tr><td colspan="5">10. FUNCTIONS AND OUT INTERFACES</td></tr>
<tr><td colspan="5">11. SYSTEM IN INTERFACES</td></tr>
<tr><td colspan="5">12. FUNCTIONAL FAILURES

13. SERIAL NUMBER</td></tr>
</table>

FUNCTIONAL FAILURE ANALYSIS
OPNAV 4790/116 (ED 2-82)

Functional Failure Analysis (OPNAV FORM 4790/116)

1. SWAB NUMBER	2. NOMENCLATURE FSI CANDIDATE		3. SHIP CLASS	SH 1 OF 105
4. PREPARED BY DATE	5. REVIEWED BY DATE	6. APPROVED BY DATE	7. REVISION DATE	
8. DESCRIPTION			9. LOCATION	10. QTY

11. FUNCTIONS	11A. IMPACT? (Y/N)
ARE ANY OF THESE FUNCTIONS NECESSARY FOR SAFETY, MOBILITY, OR MISSION?	
12. FUNCTIONAL FAILURES	12A. IMPACT? (Y/N)
DO ANY OF THESE FAILURES HAVE A DIRECT ADVERSE IMPACT ON SAFETY?	
13. RELIABILITY	13A. IMPACT? (Y/N)
IS THE ESTIMATED CORRECTIVE MAINTENANCE RATE GREATER THAN 1 PER YEAR?	
14. COST	14A. IMPACT? (Y/N)
IS THIS ITEM'S PURCHASE COST GREATER THAN $5000?	

15. MASTER FSI INDEX TRANSFER? (Y/N)	16. SERIAL NUMBER

ADDITIONAL FUNCTIONALLY SGNIFICANT ITEMS SELECTION
OPNAV 4790/117 (ED 2-82)

Additional Functionally Significant Items Selection (OPNAV FORM 4790/117)

1. SYS/SUBSYS SWAB NUMBER	2. SYSTEM/SUBSYSTEM NOMENCLATURE		3. SHIP CLASS	SH 1 OF 105
4. PREPARED BY DATE	5. REVIEWED BY DATE	6. APPROVED BY DATE	7. REVISION DATE	

8. SWAB NUMBER	9. NOMENCLATURE	10. LOCATION
		11. SERIAL NUMBER

FUNCTIONALLY SGNIFICANT ITEMS INDEX
OPNAV 4790/118 (ED 2-82)

Functionally Significant Items Index (OPNAV FORM 4790/118)

1. SWAB NUMBER	2. NOMENCLATURE	3. SHIP CLASS	SH OF
4. PREPARED BY DATE	5. REVIEWED BY DATE	6. APPROVED BY DATE	7. REVISION DATE

8. FUNCTION(S)	9. FUNCTIONAL FAILURES	10. DOMINANT FAILURE MODES	11. FAILURE EFFECTS: a. LOCAL b. SUBSYSTEM c. SYSTEM	12. TRANSFER (Y/N)
			13. SERIAL NUMBER	

FAILURE MODES AND EFFECTS ANALYSIS
OPNAV 4790119 (ED 2-82)

Failure Modes and Effects Analysis (OPNAV FORM 4790/119)

1. SWAB NUMBER	2. NOMENCLATURE	3. SHIP CLASS	SH OF

4. PREPARED BY DATE	5. REVIEWED BY DATE	6. APPROVED BY DATE	7. REVISION DATE

8. FUNCTIONAL FAILURE/ FAILURE MODE	9. CRITICALITY ANALYSIS (1)	(2)	(3)	10. CRITICALITY CLASS (A) (B) (C) (D)	11. PM TASK? (Y/N) (4, 5, 6, or 7)	12. FAILURE-FINDING TASK? (8)	13. REDESIGN? SERIAL NO.	14. TASK DESCRIPTIONS	15. PERIODICITY
								16. SERIAL NUMBER	

LOGIC TREE ANALYSIS
OPNAV 4790/120 (ED 2-82)

Logic Tree Analysis (OPNAV FORM 4790/120)

1. SWAB NUMBER	2. NOMENCLATURE					3. SHIP CLASS	SH OF
4. PREPARED BY DATE	5. REVIEWED BY DATE		6. APPROVED BY DATE			7. REVISION DATE	
8. ITEM AND TASK DESCRIPTION	9. LOCATION	10.QUANTITY	11. PREVIOUS PERIODICITY	12. MATERIAL SPECIFICATION	13. ANALYSIS DECISION	14. EXPLANATION	
					15. SERIAL NUMBER		

SERVICING AND LUBRICATION ANALYSIS
OPNAV 4790/121 (ED 2-82)

Service and Lubrication Analysis (OPNAV FORM 4790/121)

1. SYS/SUBSYS SWAB NUMBER	2. SYSTEM/SUBSYSTEM NOMENCLATURE		3. SHIP CLASS	SH OF
4. PREPARED BY DATE	5. REVIEWED BY DATE	6. APPROVED BY DATE	7. REVISION DATE	

8. ANALYSIS REFERENCE	9. LOCATION	10. EQUIPMENT NOMENCLATURE (AN, MK/MOD), APL/CID, MAINTENANCE REQUIREMENT	11. PERIO-DICITY	12. REF MRC
		13. SERIAL NUMBER		

Maintenance Requirement Index (MRI)
(OPNAV Form 4790/123)

Maintenance Requirement Index (MRI) (OPNAV Form 4790/123)

PROCEDURE EVALUATION SHEET

SHIP SYSTEM, SYSTEM, SUBSYSTEM OR EQUIPMENT	ACTIVITY/CONTRACT NO:	LOCAL CONTROL NO:	DATE PAGE OF
MAINTENANCE REQUIREMENT DESCRIPTION			MRC CODE
			DEVELOPER

RECORD			EXAMINATION	CREATE AND DEVELOP						
PRESENT METHOD	○ OP □ INSP		ANALYSIS 1. WHAT 2. WHERE 3. WHEN 4. HOW 5. WHY	IMPROVED METHOD ELIMINATE SIMPLIFY COMBINE CHANGE SEQUENCE	○ OP □ INSP		TOOLS, PARTS, MATERIAL TEST EQUIPMENT	WARNINGS CAUTIONS NOTES	RELATED MAINT	NO MEN AND RATE
	SYMBOL	TIME			SYMBOL	TIME				

Method Study and Procedure Evaluation for New Tasks and Revised Maintenance Requirement Cards (MRCs)

(OPNAV Form 4790/130)

1. SYS/SUBSYS SWAB NUMBER	2. SYSTEM/SUBSYSTEM NOMENCLATURE			3. SHIP CLASS	SH OF
4. PREPARED BY DATE	5. REVIEWED BY DATE	6. APPROVED BY DATE		7. REVISION DATE	
8. EQUIPMENT NOMENCLATURE			9. QTY. INSTALLED	10. REFERENCE MRC	
11. MAINTENANCE REQUIREMENT DESCRIPTION (TASK)				13. PERIODICITY	
12. SAFETY PRECAUTIONS				14. RATES	M/H
				15. TOTAL M/H	
				16. ELAPSED TIME	
17. TOOLS, PARTS, MATERIALS, TEST EQUIPMENT					
18. PROCEDURE					
19. SHIP'S CREW? (Y/N)	20. LEVEL: (a) (b)				
21. LOCATION		22. SERIAL NUMBER			

TASK DEFINITION
OPNAV 4790/124 (ED 2-82)

Maintenance Requirement Task Definition (OPNAV Form 4790/124)

Inactive Equipment Maintenance Requirement Analysis

EQUIPMENT:			ACTIVITY/CONTRACT NO:		LOCAL CONTROL NO:			Date Page of	
1. What degradation will occur if equipment is inactive while ship is: (a) operational? (b) in an industrial environment?	*2. Determine IEM requirements*		*3. Considering cost and resource expenditures, are the requirements of columns 2a and 2b worthwhile?*		*4. Establish IEM categories (LU, PM, SU, OT) for justified Mrs in column 3. Establish periodicity for PM requirements.*		*5. List available maintenance procedures that will satisfy justified requirements of columns 3 and 4. Indicate source (TM,OP, MRC, etc.)*	*6. Recommended IEM periodicities.*	*7. Source for IEM: (S) Existing MR (M) Modified MR (N) New develop*
	2a. What maintenance actions will protect and maintain inactive equipment?	*2b. What maintenance actions are required to reactivate equipment?*	*Yes / No*	*Justify*	*Periodicity*	*Justify*			

INACTIVE EQUIPMENT MAINTENANCE REQUIREMENT ANALYSIS
OPNAV 4790/129 (ED 2-82)

Inactive Equipment Maintenance (OPNAV Form 4790/129)

Maintenance Effectiveness Review (MER) Analyzed 08/17/2001

DISTRIBUTION STATEMENT D:

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Date: January 2002 **MIP Series:** 4111 **Periodicity:** M-1

Location:

Ship System:	Command and Control 410
System:	Data Display Group 411
SubSystem:	AN/UYQ-21(V) Tactical Data Display Set 4111
Equipment:	OJ-471(V)1,2,3 Display Control Console 4111

Rates	Man-Hours	Rates	Man-Hours	Rates	Man-Hours
ET/FC3	0.1				
Total Man-Hours:	0.1	**Elapsed Time:**	0.1		

MAINTENANCE REQUIREMENT DESCRIPTION

1. Test Overtemperature and Battle Short Indicators.

SAFETY PRECAUTIONS

1. Forces afloat comply with NAVOSH Program Manual for Forces Afloat, OPNAVINST 5100.19 series; shore activities comply with NAVOSH Program Manual, OPNAVINST 5100.23 series.

TOOLS, PARTS, MATERIALS, TEST EQUIPMENT

None

PROCEDURE

Preliminary

a. Ensure cooling water is being supplied to console.
b. Set following controls fully counterclockwise:
   (1) CRO CONTRAST
   (2) AUX CONTRAST
c. Set power control panel POWER circuit breaker to ON. Verify POWER ON indicator is lit.
d. Set power control panel DIMMER control fully clockwise.

1. Test Overtemperature and Battle Short Indicators.

NOTE 1 : **Statement of Relevance** - This task checks the battle short and the overtemperature circuitry.

a. Press and hold OVERTEMP TEST switch. Verify overtemperature buzzer sounds and OVERTEMP indicator lights.
b. Press and release BUZZER RESET. Verify overtemperature buzzer is silent and OVERTEMP indicator remains lit.
c. Release OVERTEMP TEST switch. Verify OVERTEMP indicator extinguishes.
d. Lift up BATTLE SHORT switch cover and set BATTLE SHORT switch to ON. Verify BATTLE SHORT indicator lights.
e. Set BATTLE SHORT switch to OFF and close cover. Verify BATTLE SHORT indicator extinguishes.
f. Return equipment to readiness condition.

Maintenance Requirement Card (MRC) Page 1 of 1 SYSCOM: 12 GY42 N
OPNAV 4790/85 (REV. 9-97)

MRC/MIP Preparation (OPNAV Form 4790/85)

Maintenance Effectiveness Review (MER) Analyzed 12/16/2005

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MIP CONTROL NUMBER: 2621/002-16 **Date:** January 2006

SHIP SYSTEM, SYSTEM, SUBSYSTEM, OR EQUIPMENT

Main Propulsion Lube Oil System
Level 4 - Equipment Test
2621

REFERENCE PUBLICATIONS

NAVSEA S9241-AJ-MMM-010

CONFIGURATION

Incorporates Surface Maintenance Effectiveness Review (SURFMER) Cycle 6
Incorporates Surface Maintenance Effectiveness Review (SURFMER) Cycle 30
Incorporates Ship Maintenance Effectiveness Review (SHIPMER) Cycle 51

SCHEDULING AIDS

** For scheduling purposes only; no MRC is provided.

OTHER	MRC NO.	MAINTENANCE REQUIREMENT DESCRIPTION	PERIO-DICITY CODE	RATES	MAN HRS	RELATED MAINT
	16 A7FX N	1. Test Relief Valves.	18M-2	EN3 FN	0.3 0.3	None
	16 A7FW N	1. Clean and Inspect Motor Controller.	24M-2	EM3	0.8	3001/002: U-2
	16 A7FY Y	1. Clean Coolant Side of Lube Oil Cooler.	36M-1	EN3 FN	6.0 6.0	None

UNSCHEDULED MAINTENANCE

1. Clean Coolant Side of Lube Oil Cooler. U-1 **

NOTE: Use MRC 36M-1 when lube oil outlet temperature cannot be maintained.

INACTIVE EQUIPMENT MAINTENANCE

The following requirements will be scheduled when equipment is inactivated for periods of prolonged idleness.

None required

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Appendix C

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NAVSEA/SPAWAR Technical Manual Deficiency/Evaluation Report
(TMDER) forms

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Ref: NAVSEAINST 4160.3A NAVSEA S0005-AA-GYD-030/TMMP

NAVSEA/SPAWAR TECHNICAL MANUAL DEFICIENCY/EVALUATION REPORT (TMDER)

INSTRUCTIONS: Continue on 8 ½" x 11" page if additional space is needed.
1. Use this report to indicate deficiencies, problems and recommendations relating to publications.
2. For CLASSIFIED TMDERs see OPNAVINST 5510H for mailing requirements.
3. For TMDERs that affect more than one publication, submit a separate TMDER for each.
4. Submit TMDERs at web site https://nsdsa2.phdnswc.navy.mil or mail to: **COMMANDER, CODE 310 TMDER BLDG 1388, NAVSURFWARCENDIV NSDSA, 4363 MISSILE WAY, PORT HUENEME CA 93043-4307**

1. PUBLICATION NUMBER	2. VOL/PART	3. REV/DATE OR CHG/DATE	4. SYSTEM/EQUIPMENT ID

5. TITLE OF PUBLICATION	6. REPORT CONTROL NUMBER (6 digit UIC-YY-any four: xxxxxx-03-xxxx)

7. RECOMMEND CHANGES TO PUBLICATION

7a. Page #	7b. Para #	7c. RECOMMENDED CHANGES AND REASONS

8. ORIGINATOR'S NAME AND WORK CENTER	9. DATE	10. ORIGINATOR'S E-MAIL ADDRESS	11. TMMA of Manual (NSDSA will complete)

12. SHIP OR ACTIVITY Name and Address (Include UIC/CAGE/HULL)	13. Phone Numbers:
	Commercial (___) ___-____
	DSN ___-____
	FAX (___) ___-____

Ref: NAVSEAINST 4160.3A NAVSEA S0005-AA-GYD-030/TMMP

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