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FOREWORD

I am pleased to introduce this handbook as a proven tool for developing improved preventive maintenance programs for Navy ships.

Our goal to have a fleet of reliable modern ships requires that we be effective in maintaining their readiness. Effective preventive maintenance is a key requirement. As maintainers we must focus on not one, but two objectives -- do things right -- and do the right things. This handbook introduces Reliability-Centered Maintenance (RCM), a process designed to help us achieve both of these objectives.

I hope you will find this handbook both stimulating and informative as you work to develop and implement RCM-based preventive maintenance programs in Navy ships.

S.G. CATOLA,
Rear Admiral, United States Navy
Principal Deputy Commander
for Logistics

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PREFACE

This handbook is a fourth edition of one printed early in 1979 for use as a training aid. The content has been revised considerably to:

- Respond to experience gained during the training process;
- Directly support the requirements of MIL-P-24534A (Navy).

The purpose of this handbook is to introduce you to the ideas about preventive maintenance program design that are the foundation for the method called "Reliability-Centered Maintenance (RCM)". Applying RCM requires an understanding of these ideas. Specific application also requires an understanding of each ship system, its failures, and the impact of these failures. RCM does not presume that hardware needs preventive maintenance but uses knowledge about systems, their functions, and their failures to identify applicable and effective preventive maintenance tasks.

This handbook is intended to supplement the applicable Military Specification(s), not to supplant them.

RCM provides an opportunity to apply reason -- not dogma[1] -- to preventive maintenance program design. Well used, it will provide significant benefits. Where data are limited, unstructured judgement will always be offered as an alternative to analysis. Whatever the level of data available, a structured decision logic such as that described in this handbook will provide better decisions. RCM is not a cure-all, but it is a logical way to attack important preventive maintenance task needs using the available information and knowledge that can be brought to the problem. Obviously, judgement has a role in this process. Just be sure that you use it <u>after</u> collecting the facts, not <u>instead</u> of collecting them.

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[1] A belief handed down by authority as true and indisputable.

I. INTRODUCTION TO RCM

A. HISTORY

Until recently, very few of us had given much thought to logical methods for designing preventive maintenance programs. In order to help you get quickly up to speed, the first part of this manual presents a brief review of the work done before this handbook was prepared.

There is, before 1960, no record of any effort to look deeply into the effectiveness of preventive maintenance as a process for avoiding failure. Those involved in preventive maintenance apparently believed so surely that what they were doing was correct that they saw no need to prove its truth. They reacted almost entirely to each event as it occurred rather than generalizing their experience by inductive reasoning.

In the late 50's, the new presence of jet aircraft fleets and a growing expertise in the process of analysis stimulated airline interest in improving the effectiveness of preventive maintenance for transport aircraft. Since the underlying reason for preventive maintenance is the belief that the reliability of hardware decreases with its use, the first work examined the relationship between reliability and age, using the techniques already used by actuaries in life insurance companies.

To those who believed that reliability always decreased with age, the results were disappointing. In fact, there was an unexpected discovery of the opposite -- a large number of frequent, early failures, or "infant mortality" that dominated many units' life experiences. These had been expected in electronic hardware, but not in the wide range of hardware in which they appeared. It is safe to say that infant mortality after rework is likely in all complex assemblies.

In 1967, airlines first applied decision tree logic to the problem of identifying preventive maintenance task needs. It provided an efficient approach, since it directly faced the primary question of the impact of unreliability on operations. In 1968, a decision tree logic formed the basis for the design of the initial maintenance program for the Boeing 747. Since then, similar methods have been used on the DC10, L-1011, Concorde, A-300, Boeing 767 and 757.

In the early 70's, 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 method for preventive maintenance program design, now called Reliability-Centered Maintenance (RCM), to both newly-designed and in-service aircraft -- the S-3, P-3, and the F-4. The first work by the Naval Sea Systems Command to apply this method to ships began shortly thereafter.

The prototype application to surface ships was installed in U.S.S. ROARK (FF-1053) in 1978. In mid-1979, as the result of evaluation of RCM on 4 additional FF-1052 class ships, an ongoing program for application of RCM to both new and in-service naval ships was directed by the Chief of Naval Operations. Installations have been completed, or are in process, in FF-1052, FFG-7, DD-963, LSD-41, LCAC, CG-47, ARS-50, MCM-1 and CVN-71.

B. THE BASIS FOR RCM

RCM is derived from careful consideration of the following questions. Some of these were overlooked in previous methods for selecting preventive maintenance tasks.

- What does the hardware do?
- What functional failures occur?
- What are the likely consequences?
- What can be done to prevent them?

A time-directed approach to preventive maintenance, in which the ultimate task is a scheduled, fixed-content overhaul, has been dogmatically applied to many kinds of hardware. For surface ships, in particular, very little analysis of in-service experience to validate the need for scheduled equipment overhauls has been done. In fact, the absence of really useful in-service reliability information about ship systems is the factor that constrains the potential benefits of RCM to ships.

RCM is reliability-centered. Its objective is to maintain the inherent reliability of the design, recognizing that changes in inherent reliability are the province of design.

Rather than focusing immediately on subsystems or equipments and asking "What preventive maintenance can be done?", RCM starts from the top by:

- Partitioning the ships into systems and subsystems that require analysis;
- Identifying additional functionally significant items;
- Determining the maintenance requirements (tasks) for each significant item based on analysis of its functions, both evident and hidden, and its dominant failure modes;
- Determining when, how, and by whom each task will be done;
- Identifying needs for design change when safety is threatened by a failure for which there is no applicable and effective task; and
- Using information obtained from operations and appropriate analytical techniques to adjust these intervals and revise task content.

C. The ENVIRONMENT

In the past, there has been a distinct separation between "organizational maintenance" and other maintenance performed by shore activities. This separation has applied to maintenance requirements planning, the processes for determining maintenance requirements, and the documentation of these requirements and of work done. Coordination, if any, has usually been incidental.

Recently, recognition of the desirability of reducing organizational (on-ship) maintenance resource requirements has resulted in progress toward coordination, if not integration, of planning for the total preventive maintenance requirements for some ship classes. (If you are familiar with the LO-MIX and DDEOC concepts, you will recognize this progress.)

To achieve its objective of applicability and effectiveness, preventive maintenance must be a cohesive set of requirements that, together, represent a harmonious, orderly set of tasks performed by the maintenance resource at large. Hardware cannot react to where or by whom preventive maintenance is done, only to what is done.

The task of the manager(s) of preventive maintenance requirements is to organize the processes for establishing and maintaining these requirements so that for the life of the affected hardware, they have the highest degree of applicability and effectiveness.

At present, considerably more can be done to achieve that objective. A suggested ultimate objective is to:

- Integrate the responsibility for life cycle preventive maintenance program management for each ship class.
- Bring the resources of the design engineer, in-service technician/mechanic and maintenance analyst together when developing or changing preventive maintenance programs.

D. SCOPE

The application of RCM described in Military Specification MIL-P-24534A (Navy) is focused on systems. Although prior methods for developing preventive maintenance requirements have dealt primarily with systems needs at the organizational level, this specification is intended to be applied to the development of life-cycle preventive mai[illegible]ce requirements for all hardware, including structures, [illegible]val ships.

II. PRINCIPLES AND THEORY OF MAINTENANCE

This section of the handbook serves to review some basic ideas that underlie the performance of tasks to prevent or discover failures.

A. WHAT KINDS OF MAINTENANCE ARE THERE?

Let's get first things first. What kinds of maintenance are there? The answer depends on one's breadth of view. Certainly, there is preventive maintenance -- the activity intended to prevent functional failures or discover them. There is also corrective maintenance -- the activity intended to return failed equipment to operating condition. If you consider the modification (alteration) of hardware to be a kind of maintenance, then we could call that alterative maintenance -- an activity intended to eliminate failures by changing design.

This handbook addresses only preventive maintenance.

B. WHAT IS A FUNCTION?

A function is a capability of a system, equipment, or lesser item that is a specific requirement of the design.

There are two kinds of functions that we must consider when determining preventive maintenance task needs:

- On-line -- Primary functions operated either continuously or so often that the user has current knowledge about their state (for example, the function provided by the boiler feedwater pumps).
- Off-line -- Primary functions operated under the user's control but used intermittently or so infrequently that their availability is not known by the user without some special check or test (for example, the functions provided by most weapons).

  Secondary functions that are hidden from the user because there is no immediate indication of malfunction or failure. The demand for such functions usually follows another failure (for example, the functions provided by emergency systems and automatic protective devices).

Often some piece of hardware performs several functions. Some may be so simple they are overlooked. For example, the elements of any fluid system have the elementary function of containing the fluid as well as controlling its flow or pressure. Systems also often include self-protective and information functions.

We must also recognize that functions may be either active (there is some kind of output) or passive (such as containment or insulation).

In your analysis to determine the need for preventive maintenance tasks, you will review each function of a system to identify its dominant failure modes. (These functions will include objective outputs (including status reporting), protective functions, passive functions, and output interfaces to other systems.)

C. WHAT IS A FAILURE?

A failure is simply the presence of an unsatisfactory condition, a condition that is unsatisfactory to a particular observer in a specific situation. As a result, if failure information is to be of the most value, it must carry with it some knowledge about the relevant conditions.

A watchstander in the engine room may often observe and record the failure of some redundant element in the Fuel Oil Service System, but the Captain will not necessarily be conscious of such a failure as long as the propulsion system is able to meet his needs. Therefore, a question about the prevalence of failures of this kind would result in entirely different answers from the watchstander and the Captain.

Similarly, the "oil kings" on different ships may use the Fuel Oil Service System in such different ways that resultant instances of failure are very different, even though the equipment is exactly the same.

Our primary objective is to maintain function as perceived by the Captain, not by the watchstander.

D. FAILURE DETECTION

Failures may be detected while performing specific operating duties, or by casual observation by the crew, or they may be discovered as the result of a specific preventive task. Such failures are "functional failures," the inability of an item (system-equipment-unit-part) to meet a specified performance standard. A complete loss of function is clearly a functional failure; so is the inability to perform at the minimum level defined as satisfactory.

Having defined a specific functional failure, it may be practicable to identify or define some pre-failure condition that indicates that a failure is imminent. Such a condition is called "potential failure." The ability to define and detect potential failures is a very important part of modern maintenance program design. (The decrease in output of a pump or a radio transmitter below some specific performance standard are examples of potential failures.)

E. CONSEQUENCES OF FAILURE

The most important consequence of a failure is a threat to safety. A threat to safety is one which threatens life, limb, or health of the crew or others. Threats to the condition of equipment are not included.

The next most important consequence of a failure is a threat to operational capability. Such consequences are economic in the broad sense. Measures of such consequences must include the imputed cost of lost operational capability. Keep in mind that if a system that provides operational capability has redundancy which prevents some failures from causing loss of system functions, then loss of operational capability is not a consequence of single failures.

Last in the order of consequences of failure is a threat to functions that are not included above. Most of these are support functions. Some are functions that provide operational capability but have either on-line or switching redundancy. (Failure to understand the attributes of redundancy is a common error among operating personnel.)

Failures of hidden or infrequently used functions have no immediate consequences. Nevertheless, their ultimate consequences may have a severe impact on safety or operational capability. This result may be particularly severe if the hidden function, in fact, provides backup for what otherwise would be a safety-critical or operationally-critical functional failure.

F. FAILURE DATA

The thirst for failure data appears to be insatiable. Yet, the experience of the professional analyst is that often the data being collected are not useful. Since it is absolutely impracticable to collect everything, it is important that the users of data present an ordered list of the information needed to support their work. Developers of maintenance programs need the following information (placed in order of decreasing failure consequences):

- Failures that could have a direct effect on safety;

- Failures that have a direct effect on operating capability;
- Failure modes of units involved;
- Causes of potential failures (results of condition-directed tasks);
- The general condition of unfailed parts in units that have failed; and
- The general condition of unfailed systems.

All failure data must be accompanied by data describing the activity of the unit population. To be useful these data must:

- Be complete (include all failure events in the period analyzed).
- Be accompanied by an appropriate activity (or stress) parameter (e.g., total unit operating hours during the same period).
- Identify specific location (if there are multiple installations in a ship).

The lack of information of this quality does not disable RCM, but it reduces its benefits, particulary those related to improving an initial program based on operating experience.

NOTE:
This information makes the calculation of unit mean time between failures (MTBF) possible, but it still is not sufficient to support a need to understand the effect of age on reliability. For this capability, these additional data are required:

- Identification of each failed unit (its location and serial number)
- The age (cumulative stress) of each unit installed or removed
- Conditions found in the failed units.

G. MULTIPLE FAILURES

Multiple failures are a specter that threatens ship commanders. Although specters are immune to conventional weapons, they are vulnerable to truth.

Multiple failures are of two kinds:

- The occurence of more than one independent event; and
- The occurence of associated events (common cause).

We are often frightened by events of the second kind and, as a result, are made fearful of events of the first kind. Keep in mind that these two kinds of failures have nothing in common but their result.

The probability of multiple independent failures, even if the expected failure rate is moderately high, is quite low. Given a unit failure rate of 1 failure per 100 operating days and both units on-line, the expected occurrence of 2 failures in the same operating day is only 1 in 10,000!

If the repair time for the first failure is one operating day or less, even a potentially critical functional failure (both units failed) is extremely unlikely. The probability of multiple common cause failures is also very low, provided the designer had done his job well, considering both internal and external threats. These failures depend on normally unpredictable events, ranging all the way from careless operations to Acts of God. The message is very simple. Do not encumber the crew with doubtful preventive maintenance tasks in an attempt to minimize multiple failures. In your zeal to do so, you may create a high risk of common cause failures caused by maintenance errors while attempting to prevent independent failures.

Common cause failures are not likely to respond to a preventive maintenance task.

Of course, these comments relate to tasks intended to prevent failures. There is an important need, when system design provides redundancy, to be assured that it, in fact, exists. This need will be described further in the section on Failure-Finding Tasks.

H. THE FAILURE PROCESS

All of us learn to accept failures as a part of living with hardware. In some cases, it is easy to find ways to eliminate failures by changing design. In other cases, the function we need requires a great deal of complexity, and we are forced to accept a high failure rate as a trade-off for having that function, even though its availability may be less than we would like.

The role of preventive maintenance is to decrease or prevent these failures. Let's make sure that we have an understanding of the failure process.

If we can visualize that a simple item like a pump shaft or a gear has a quality we can call "resistance to failure" and that use of this item subjects it to "stress", then "failure" occurs when the stress exceeds the resistance to failure. Figure II-1 presents this idea graphically.

Excess resistance to failure can be provided by excess material that wears away, or is consumed, or simply provides extra strength that is subject to loss from corrosion or fatigue. The resistance to failure of simple items usually decreases with use or time (age).

Stress is dependent upon use and may be highly variable. It may increase, decrease, or not change with use or time. If you reviewed the failures of a large number of nominally identical simple items, you would very likely find they had about the same age at failure and that these failures occurred for the same reason. You can see, if we are considering preventive maintenance for some simple item and can in some way measure resistance to failure,[1] we can use that information to help select a preventive task.

Now let's consider a very complex unit that consists of hundreds of interacting simple items (parts) and has a considerable number of failure modes. In this case, the mechanism of failure is the same, but it is operating simultaneously and interactively on all these parts so that failures no longer occur for one reason or at about the same age. For these units, it is likely that an effective task can be designed only when there are a few dominant or critical failure modes.

If these dominant or critical failure modes can be eliminated by some change in design, then the previously effective task will no longer be effective and the maintenance program designer must look elsewhere.

[1]Or something that is highly correlated to it.

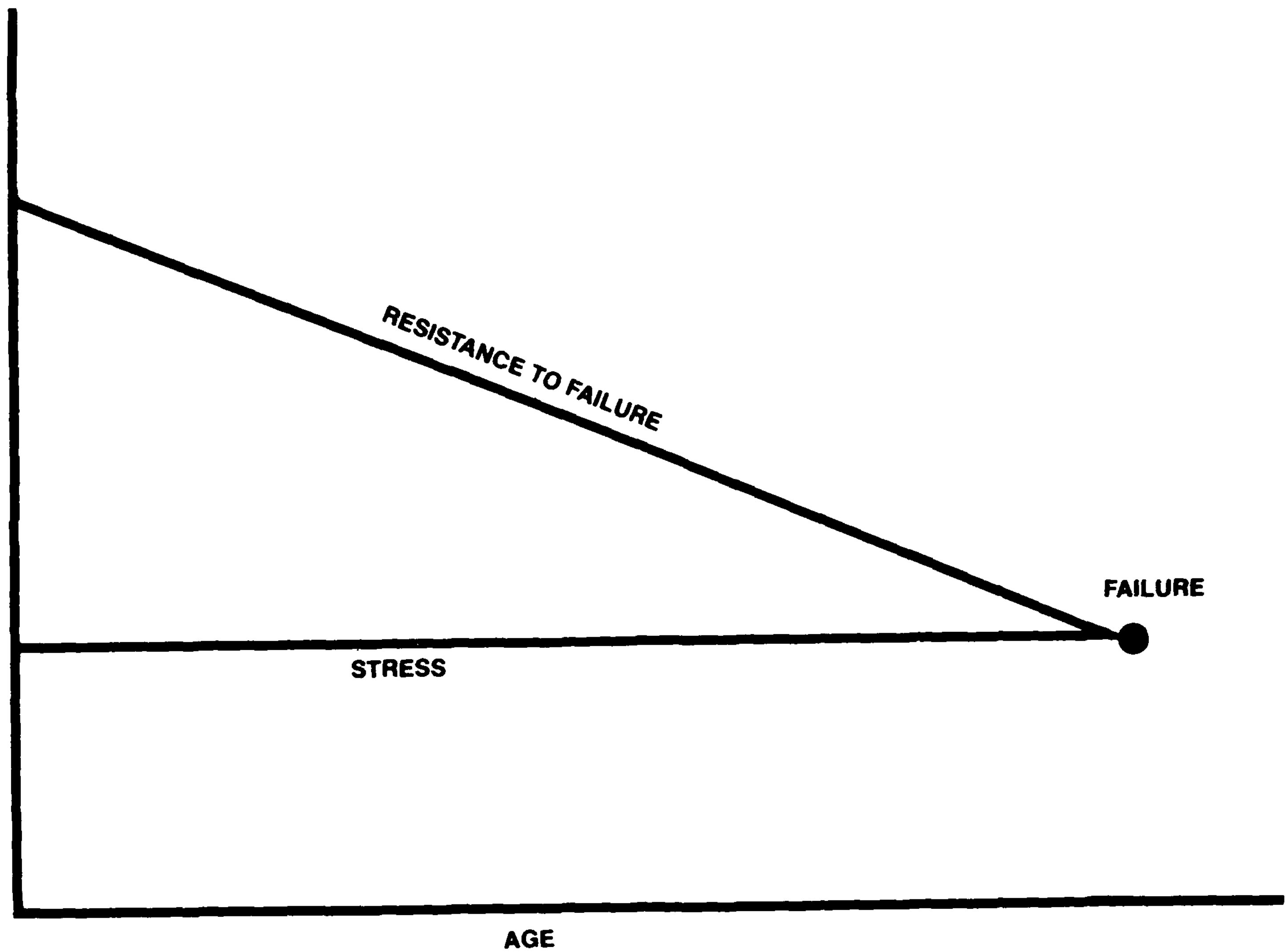

Figure II-1

THE FAILURE PROCESS

SUMMARY

1. Preventive maintenance is an activity intended to prevent functional failures or discover them.

2. A function is a capability of a system, equipment or lesser item that is a specific requirement of the design.

3. Functions can be on-line or off-line, active or passive.

4. A failure is the presence of an unsatisfactory condition.

5. Failures may be detected while performing specific operating duties, by casual observation, or by specific failure-finding tasks.

6. The most important consequence of failure is a threat to safety. Next most important is a threat to operating capability.

7. Available failure data often are not useful to support maintenance program design adequately.

8. The threat of multiple failures is often overestimated.

9. Failures result when stress exceeds resistance to failure. For complex systems or equipment, the multiplicity of parts and failure modes often causes failures to occur over a wide range of ages, reducing or eliminating the potential effectiveness of preventive maintenance.

III. PREVENTIVE MAINTENANCE TASKS

We do preventive maintenance (PM) because we believe that doing some task in accordance with a predetermined plan or specification will prevent or discover hardware failures before they have an impact on safety, or operations or some important support function. This plan or specification has at least two elements: what and when. It may also include who, where, why and how.

This section of the handbook addresses the kinds of preventive tasks available to you and their specific application.

The whole idea of preventive maintenance rests on the belief that, all things considered, the user will be better off by doing a PM task than by not doing it. The Navy will be better off if either the task effectively prevents failures affecting safety, or, for all other failures, it provides benefits that exceed the cost. (Of course, cost in this case includes the imputed cost of lost mission capability.)

What are the potential preventive maintenance processes? When considering the prevention of a functional failure we have three alternatives:

- Select a time-directed task;
- Select a condition-directed task; or
- Do nothing.

If it is not practicable to prevent a functional failure and that failure is not evident to the crew during normal operations, we have an additional alternative:

- Select a failure-finding task to discover the failure.

A. TIME-DIRECTED TASKS

A time-directed task is one performed at a specific interval without consideration of other variables. The task interval may be either a specific period of time or one determined by the number of certain events since some previous action.[1] The task may require either specific action resulting in continued use or

[1] Rounds fired, for example

reuse (RW-rework), or specific action requiring that the item be discarded and replaced with a new item of the same kind (LL-life limit).

Examples: Remove the RADAR ANTENNA for rework (RW) annually.
Replace the PERSONNEL BOAT ENGINE LUBE OIL FILTER (LL) every 500 operating hours.

B. CONDITION-DIRECTED TASKS

A condition-directed task (CD) is one performed at a specific interval (or after a number of specific events) that compares observed condition(s) with an appropriate standard.

Example: Inspect the CHILLED WATER CIRCULATING PUMP for external leaks weekly (CD). No leaks permitted.

C. FAILURE-FINDING TASKS

A failure-finding task (FF) is one performed at a specific interval to find functional failures that have occurred but are not evident to the operating crew.

Unlike the previously described kinds of tasks, failure-finding tasks do not prevent functional failures; they discover them. They are preventive only in the general sense that they prevent surprises by revealing failures of hidden or infrequently-used functions.

Example: Test the STEERING CONTROL SYSTEM AUTOMATIC CHANGEOVER TRANSFER SWITCH quarterly.

D. TASK SELECTION

Each task selected must meet two requirements:

- It must be applicable; and
- It must be effective.

Applicability depends on failure characteristics. An applicable task must either prevent or reduce the impact of failures. (An inapplicable task may in reality increase failures, or simply have no effect.) Effectiveness measures result and depends on failure consequences. Figure III-1 summarizes the applicability and effectiveness criteria for all of the task alternatives discussed above.

E. SERVICING AND LUBRICATION

Servicing and lubrication tasks may be either time-directed or condition-directed. These tasks can be identified by use of the RCM logic; in fact, the logic may identify some special servicing or lubrication need. The RCM process requires a common sense review of existing requirements and a review of the manufacturer's recommendations to be sure that all of the ship's requirements are identified and excessive needs are deleted.

The ability to evaluate servicing and lubrication requirements depends greatly on the availability of "conditions found" information. If you lack this information, you will have difficulty specifying applicable and effective servicing and lubrication tasks.

F. GENERAL INSPECTIONS

As originally developed for application to aircraft, the RCM process provided for a set of general inspections. These were called "zonal" inspections because they were directed to areas and spaces which together exhaustively covered the entire aircraft. Zonal inspections provided a means for aggregating minor inspections of all kinds that were within the capabilities of any journeyman mechanic. (In most cases, these inspections could be considered to be integrity inspections such as checks for leaks, overheating, broken hardware, etc.)

In Navy ships, a somewhat different situation exists:

- The crew occupy or frequently visit most of the ship's spaces during operation, and
- There is already a process for assuring the general condition of all spaces and availability of damage control equipment.

Therefore, the zonal inspection process, a normal part of an RCM-oriented preventive maintenance program for aircraft, is not applied to ships.

Figure III-1

TASK APPLICABILITY AND EFFECTIVENESS CRITERIA

TASK	APPLICABILITY	EFFECTIVENESS
Time-Directed		
Scheduled Rework (RW)	Probability of failure must increase at an identifiable age. A large proportion of units must survive to that age.	For critical failures: The task must reduce the risk of failure to an acceptable level.
		For all other failures: The task must be cost-effective.
Scheduled Life Limit (LL)	For safe-life items: Probability of failure below life limit must be zero.	A safe-life limit must reduce the risk of failure to an acceptable level.
	For economic-life items: Probability of failure must increase at an identifiable age. A large proportion of units must survive to that age.	An economic-life limit must be cost-effective.
Condition-Directed (CD)	Reduced failure resistance for a specific failure mode must be detectable. Rate of change in failure resistance must be reasonably predictable.	For critical failures: The task must reduce the risk of failure to an acceptable level. For all other failures: The task must be cost-effective.
Failure-Finding (FF)	Occurrence of functional failure must not be evident to the operating crew during performance of their normal duties.	The task must increase availability of the affected function to an acceptable level.

SUMMARY

1. There are three alternatives when considering prevention of a functional failure:

- Select a time-directed task;
- Select a condition-directed task; or
- Do nothing.

2. If a specific failure is not evident to the crew and cannot be prevented, there is an additional alternative:

- Select a failure-finding task

3. Each selected task must be both applicable and effective.

4. Although the RCM logic will obviously bring some servicing and lubrication tasks to mind, these can be entered in the servicing and lubrication analysis which requires review of the manufacturer's recommendations, or previous PM tasks.

5. General (area) inspections used in aircraft RCM applications are not used in ships.

IV. THE APPLICATION OF RCM

RCM is a methodology intended for use in developing the preventive maintenance tasks which, together, comprise the preventive maintenance program for a ship. If you are involved directly in the application of RCM, you should understand that intention. Otherwise, you may focus on some lesser level of assembly and its function rather than on how it, in concert with other hardware, provides all the functions of the ship.[1]

If you recognize that safety transcends mission, and mission transcends support functions, then you will understand that for each of these, different levels of effectiveness, and perhaps resources, should be required.

You will obtain the most effective results by working as closely as possible with associated system specialists who also understand the "ship objective." This close association can be achieved either physically or by active, perceptive, communicative management of separate activities.

Experience has highlighted the critical importance of:

- Careful initial identification and partitioning and easy ways to amend the initial system and subsystem boundaries;
- Initial discussion between the developers and the In Service Engineering Agents (ISEA) to obtain the ISEA's insights and ensure that the analysis gets off on the right track;
- Selecting analysts who have a tenacious curiosity about how things work, why they exist, and what PM tasks really are applicable and effective; and
- Independent quality assurance reviews.

A. ANALYST AND STAFF SELECTION AND TRAINING

The ideal staffing for applying RCM recognizes the need for 3 specific skills.

- An understanding of the system's design from the viewpoint of the designer (an engineer).
- An understanding of how the system is, or will be, used, and of its dominant failures and operating characteristics (a ship's work center supervisor).

[1] This is a common error by inexperienced analysts when applying RCM.

- An understanding of in-service reliability analysis and preparation of maintenance requirements documents (a 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/technician teams to work on systems familiar to them and, if practicable, locate them at the hardware site. The third skill can be provided by a specialist who serves all teams on a particular project.

The staff also should include an independent, technically qualified person who reviews all documents to ensure that they are technically correct and comply with the applicable standards and specifications.

Preparing an RCM-based preventive maintenance program requires training in RCM concepts and in use of the documentation specified in MIL-P-24534A. It's also important that you and other members of your team be very familiar with the design, operating characteristics and operating experience of the systems assigned.[1] Arrange for periodic meetings of all teams on your project to discuss ideas and problems associated with each documentation step in the RCM process. These meetings will accelerate the learning process and avoid many potential pitfalls that may occur as you work on your assigned system(s).

Do not use existing Planned Maintenance System (PMS) documentation as a training resource.[2] Preparing an RCM-based program is intended to be an innovative, creative search for applicable and effective tasks. You will do a better job by thinking about what should be done than by reviewing the PM tasks that are being done on the system(s) to which you are assigned.

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[1] If you feel you need more knowledge about preventive maintenance, see Nowlan and Heap, Reliability-Centered Maintenance DDC AD 4066579, 1979.

[2] Retrofitting an RCM-based program on an existing ship class will require access to this documentation as a means for identifying failure modes ONLY, not for training or familiarization purposes.

B. INFORMATION COLLECTION

Technical information is required for each ship system and its equipments.

- 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 use as a source of information after tasks have been identified and for identifying failure modes and functional failures for retrofit applications)

Acquisition and distribution of this information is best handled as a specific assignment under the direction of the Project Manager. This work requires a high level of knowledge about the most useful sources of this information and the processes by which it can be most expeditiously obtained for the various kinds of systems and equipments involved.

C. SYSTEM IDENTIFICATION AND PARTITIONING

Your first task is to identify all of the ship's systems and partition them in a logical way. The Ship Work Authorization Boundaries[1] will be used to identify all ship systems. (See Table IV-1.) A further breakdown of these systems to the equipment level will be required. The Ship Systems Definition and Index (SSDI) prepared for the FFG-7 class ships is a typical example of what must be done (See Figure IV-1.)

This breakdown must be done for the ship, not separately for each SWAB Group, otherwise there is a high risk of gaps and overlaps. A system is "a set or arrangement of things so related or connected as to form a unity or organic whole."[2] This definition permits two quite different perceptions -- unity as a

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1 NAVSEA 0900-LP-098-6010 (for surface ships)

2 New World Dictionary, Second College Edition

collection of like things (e.g., a collection of all antennas) or an organic assembly (e.g., a fuel system). Given a choice, you will find that the organic approach simplifies analysis. It links inputs to outputs. The collection approach may put inputs in one system and outputs in another. If you find that the SWAB is inappropriate for logical analysis, propose an appropriate breakdown for use in your task to your PMS Coordinating Activity.

No matter how you finally decide to structure each system, be sure that you (the analyst) and the final technical reviewer agree on the content and structure of each system before you go any further.

TABLE IV-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	Habitational and sanitary systems, furnishings, and services.
700	Armament	Offensive and defensive weapon systems.

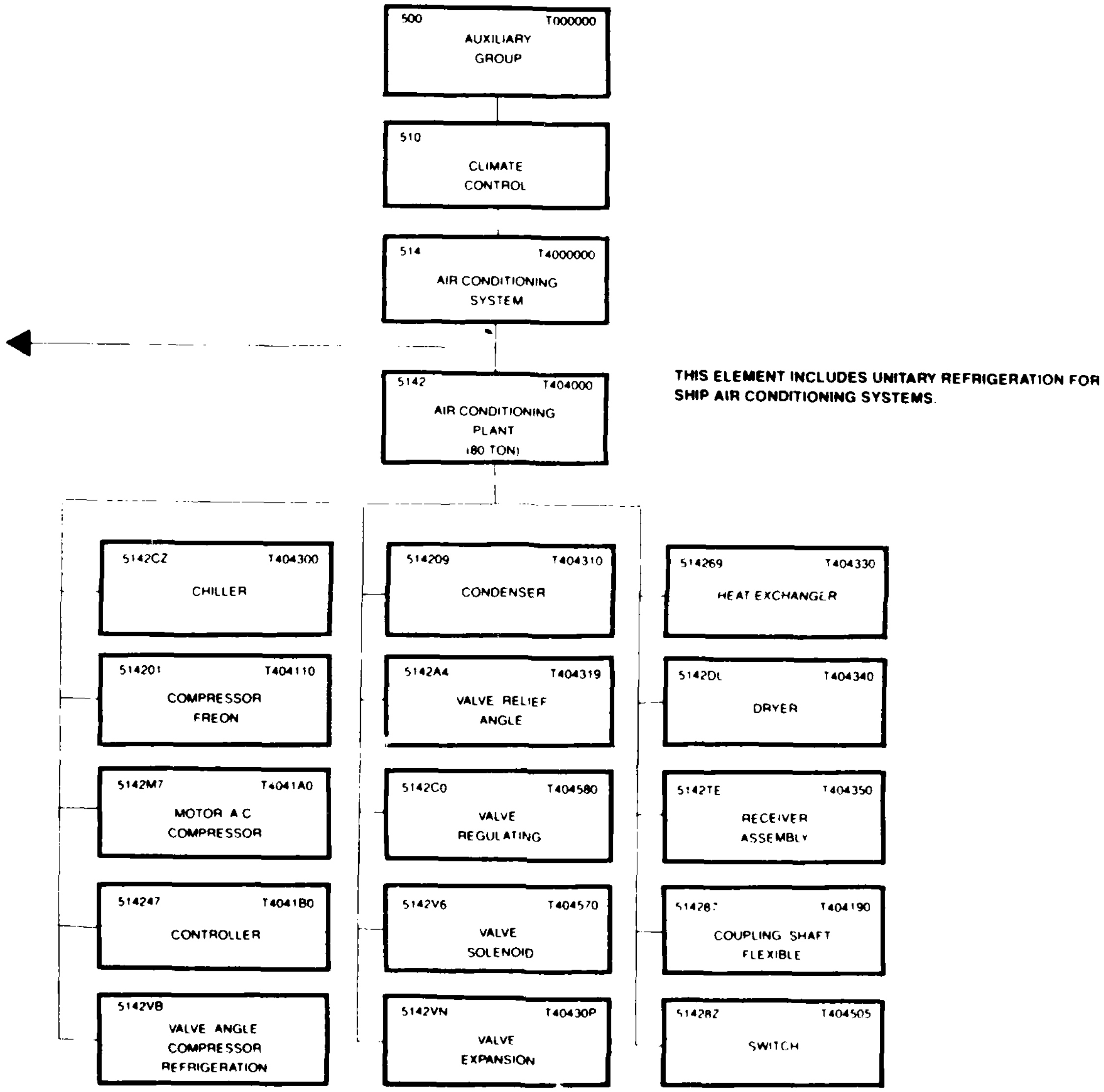

Figure IV-1

SAMPLE FFG-7 SSDI PAGE

D. ANALYSIS OF SYSTEMS

The RCM method requires analysis of preventive maintenance requirements at the system and subsystem levels. The need for analysis below the subsystem level depends on the complexity of the system and your knowledge and expertise.[1] You will do less "dog work" if you do not go below the subsystem level. Nevertheless, understanding all of the functions of a complex system and selecting applicable and effective tasks to maintain them may require that you go, selectively, to the equipment level or below. You will do fewer of these lower level analyses as you become more expert.

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.

E. DEFAULT STRATEGY

If you have limited operational knowledge about a particular functional failure, you may lack confidence about your ability to answer a question in the RCM Decision Logic Tree.

The default strategy describes how you should act if you feel that you have inadequate information on which to decide upon the need for a task. The idea is that if you cannot make a final decision, you make an interim one that minimizes risk. Later, you can update it when you have more knowledge. The default strategy for each of the decision tree questions is shown in Figure IV-2.

---

[1] If you believe that for any system you must analyze the functions of each equipment item, you have the wrong perspective. Reread the first paragraph of Chapter 4.

Figure IV-2

DEFAULT STRATEGY

DECISION QUESTION	DEFAULT ANSWER
1. Is the occurrence of a failure evident to the operational crew while it is performing its normal duties?	No—(except for critical secondary damage). This answer classifies functions as hidden or infrequent.
2. Does the failure cause a loss of function or secondary damage that has a direct and adverse effect on operating safety?	Yes—This answer classifies functions as critical.
3. Does the failure have a direct and adverse effect on operational capability?	Yes—This answer classifies functions as operational.
4. Is there an applicable and effective preventive maintenance task (or combination of tasks)?	Yes—if the potential task is a CD task. Make the task interval short enough to be effective. No—if the potential task is a rework or discard task and safety is not involved. Yes—if the potential task is a rework or discard task and safety is involved.

F. PERIODICITY

Although numerous ways have been proposed for determining the correct periodicity of preventive maintenance tasks, none are practicable, unless you know the in-service age-reliability characteristics of the system or equipment affected by the desired task. This information is not generally available for ship systems and equipment.

Careful analyses of similar kinds of hardware in the commercial airline community have shown that, overall, more than 90% of the hardware analyzed had no adverse age-reliability relationship. This does not mean that individual parts do not wear; they do. It means that the ages at failure are distributed in such a way that there is no value in imposing a preventive maintenance task. In fact, in a large number of cases, imposing a so-called preventive task actually increases the average failure rate.

If you are convinced that a periodic preventive maintenance task is necessary, it is unlikely that, from the available information, you can select the best periodicity. Do not fall into a trap by believing that the failure rate, or its inverse, the Mean Time Between Failure (MTBF), is a proper basis. It is not. Why? Because it does not give you any information about the effect of increasing age on reliability. It only gives you the average age at which failure occurs. The best thing you can do if you lack good information about the effect of age on reliability is to pick a periodicity that seems right. Later, you can personally explore the characteristics of the hardware at hand by periodically increasing the periodicity and finding out what happens. Chances are that in most cases you'll be able to make significant increases without adverse results.[1] When you want to establish the periodicity of a failure-finding task, some assumptions about the failure distribution of the affected hidden or infrequent function make the calculation somewhat simpler.[2] Here is a suggested solution:

$T = -\theta \log_e (2A-1)$ where: T is the task periodicity
θ is the no-task MTBF
A is the desired/expected availability

<u>Example</u>:

<u>No-task MTBF</u>	= 50 hours (an estimate)
Desired/expected availability	= .95
Task periodicity (T)	$= -50 \log_e [(2 \times .95) - 1]$
	$= -50 \log_e .90$
	$\approx$ 5 hours

NOTE:
This solution assumes exponential survival and no adverse impact of test on future reliability. If the test actually degrades reliability, then the testing interval should be longer.

---

1 This practice is obviously not to be used when failures have a direct adverse effect on safety; then a controlled test is required.

2 Assumes that the availability of the function decreases at a constant rate (exponentially).

G. ECONOMICS AND COST EFFECTIVENESS

This section of the handbook has made several references to economics and cost effectiveness. Those words, while commonplace in a commercial environment, are relatively unfamiliar with the military environment. Nevertheless, they underlie some of the most powerful decisions associated with the selection and design of weapons and support systems. Keep in mind that the ship has a particular system because of a cost/benefit decision. You may not be able to find the numbers neatly set down anywhere, but set down or not, they existed at some time in the mind of a decision-maker.

If you are charged with the responsibility for designing a maintenance program or selecting a preventive maintenance task, you have a similar responsibility. Remember this statement from Section III of this handbook:

> The whole idea of preventive maintenance rests on our belief that, all things considered, the user will be better off doing a PM task than by not doing it.

Note that the task must make the user, not the analyst, better off.

We've already established the critical importance of failures that are a threat to safety. Assurance that a ship and its systems are safe has sufficient value that we exclude effective safety-related tasks from our economic considerations.

For non-safety-related functions or functional failures, we must consider economics. We do this in the form of trade-offs, the idea being to decide whether the user will be better off by doing a PM task than by not doing it.

Our measure is called cost-effectiveness. Cost-effectiveness is a measure of the efficiency of our use of resources to obtain some benefit; it is not just a case of being cheap.

When you make these trade-offs, these ideas should be helpful:

- Your application of economics will not require a great deal of precision. Most of your work will simply consist of finding the alternative which is biggest, or smallest, not how big it is;

- For mission-related functions, if you are convinced that a task is applicable (that is, you know that it works)[1] and the periodicity required to make it effective is practicable, you've probably got a good task; and
- For a non-mission-related function, if you are convinced that the task is applicable,[1] using the required periodicity, estimate the annual cost of doing the task and compare it with the annual direct cost of failures you expect to prevent.

---

[1] Review Figure III-1

V. DEVELOPING A PREVENTIVE MAINTENANCE PROGRAM

In previous chapters we have discussed a wide range of things -- history, principles, kinds of tasks -- but we have not yet addressed any method for using the knowledge we have acquired. If you can keep what has already been discussed clearly in mind, it can improve your 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.

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

When directed by the PMS Coordinating Activity, we may use the existing PM tasks as input to our analysis, identifying for each system, all of the functional failures and the failure modes (and their effects) that each existing task is intended to prevent or control.

A. DESIGNING AN RCM-BASED PREVENTIVE MAINTENANCE PROGRAM (MIL-P-24534A)

The process for designing a preventive maintenance program using RCM-based methodology is shown in Figure V-1. The following steps are required:

- Master Systems and Subsystems Index;
- Functional Failure Analysis;
- Additional Functionally Significant Item Selection;
- Functionally Significant Items Index;
- Failure Modes and Effects Analysis;
- Decision Logic Tree Analysis;
- Servicing and Lubrication Analysis;
- Maintenance Requirements Index;
- Task Definition; and
- Safety-Related Design Change Recommendation.

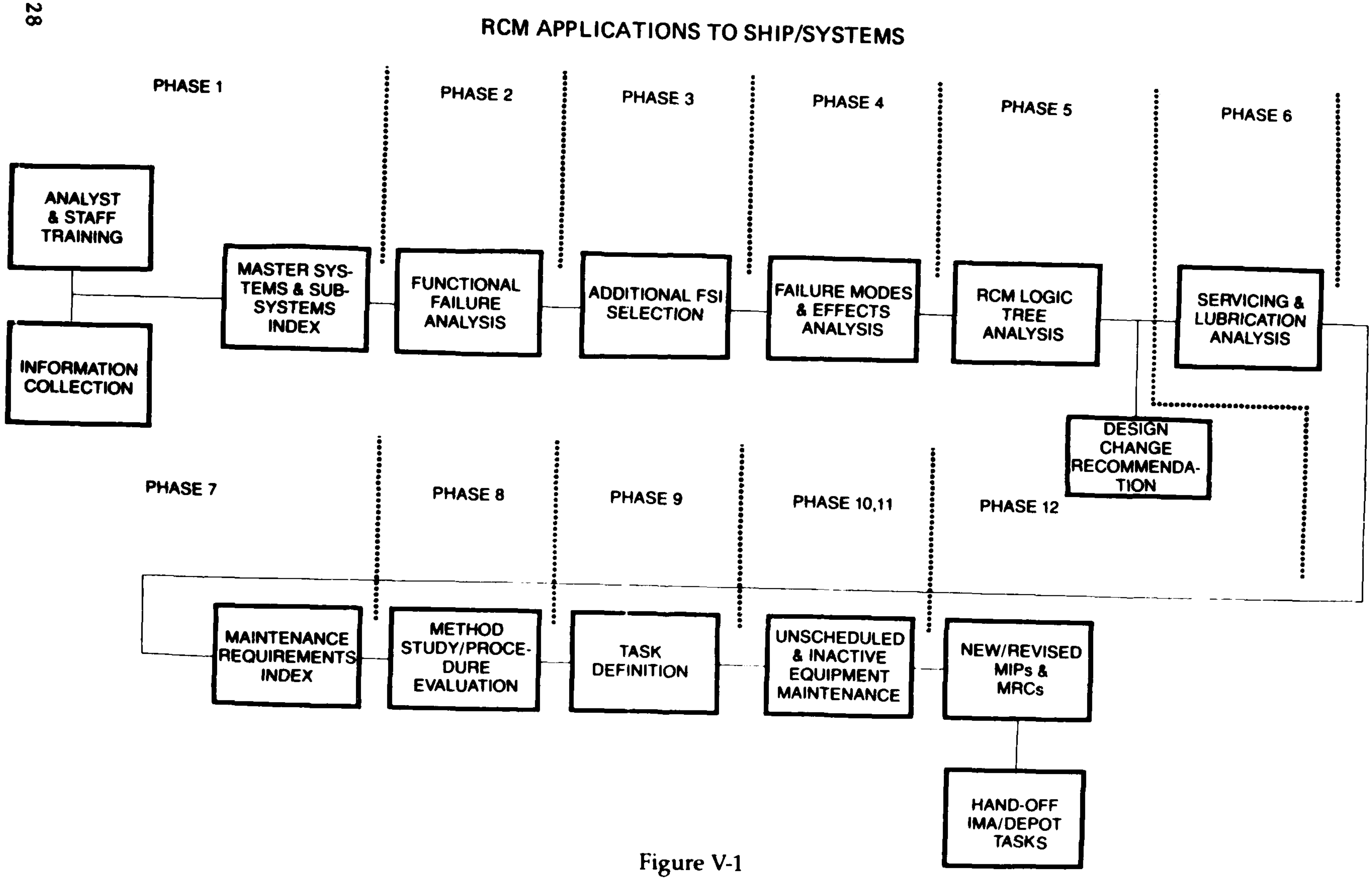

Figure V-1

PM PROGRAM DESIGN FLOWCHART

B. MASTER SYSTEMS AND SUBSYSTEMS INDEX (OPNAV 4790/114)[1]

Developing a preventive maintenance program at the ship level requires that a master index be prepared so there is a means for making a set of mutually exclusive and exhaustive development assignments. The Master Systems and Subsystems Index is based on the Ship Work Authoriziation Boundaries previously shown in Figure IV-1[2]. If a Ship Systems Definition and Index (SSDI) or Ship's System Staging Diagram (SSSD) has been prepared for the ship, it should be the source used to prepare this index.[3]

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

- A system contains different equipments than those shown in the SSDI/SSSD;
- Equipments have been shown in the wrong system; or
- A system was perceived as a "set of things" (such as antennas) rather than as a source of functions.

These revisions should be discussed with your PMS Coordinating Activity.

C. FUNCTIONAL FAILURE ANALYSIS (OPNAV 4790/116)

The Functional Failure Analysis (FFA) is required for RCM applications. You will prepare an FFA for each system and subsystem listed in the Master Systems and Subsystem Index. Its purpose is to provide a description of each system and subsystem, to identify all functions and interfaces with other systems and to identity all functional failures (including failures of output interfaces).

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

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[1] This is the OPNAV form number.

[2] NAVSEA 0900-LP-098-6010

[3] Some changes may be necessary to facilitate analysis.

If a system includes subsystems which in themselves are at least as complex as the system discussed above, you will prepare FFA's for the system and for each of its subsystems. Before attempting to prepare these FFA's, prepare (or obtain) a block diagram that shows the functional elements of the entire system and the interfaces between it and other systems. Be sure that you understand which functions are unique to each subsystem and which functions are provided by the system as a whole.

This analysis requires a brief narrative description and specific identification of design features that provide redundancy, protective devices, or other fail-safe design provisions. Identification of Built-In Test Equipment (BITE) or condition indicators is also required. Keep in mind that your purpose is to learn enough about each system to lead you to potential sources of system functional failures.

Each system or subsystem can have one or more functions. Identification of all functions requires careful study.[1] Make sure that you are not overlooking important passive functions. (A fluid system that provides a supply of water also holds it. A leak is a failure!). It is important to recognize that loss of a passive function may be significant, even though the system may not be operating at the time of failure.

A functional failure exists when a system or subsystem ceases to provide a required function. Note that some functions are active (loss of the required activity constitutes failure) while some are passive (activity constitutes failure). 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 failure is of primary importance. Whenever a 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 failure has occurred.

D. ADDITIONAL FUNCTIONALLY SIGNIFICANT ITEM SELECTION (OPNAV 4790/117)

For new ships or systems, all systems and subsystems listed in the Master Systems and Subsystems Index are Functionally Significant Items (FSIs). You may select other FSI candidates from lower indenture levels by review of the system block diagram

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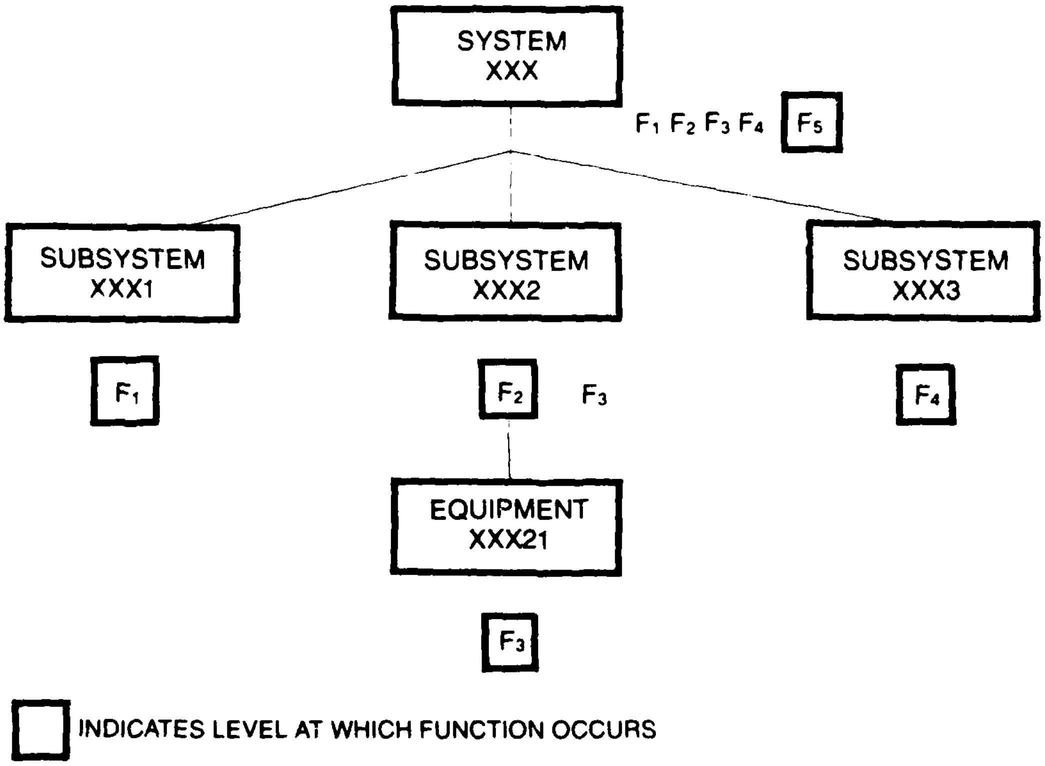
[1] Be sure to include self-protective and information functions.

and validate these by using the Additional FSI Selection form. Careful completion of the FFAs should provide you with the knowledge necessary for making additional FSI selections.[1]

When you have completed this phase of the development process, you should have:

- A single FSI for the entire system; or
- FSIs for the system and each subsystem, but not for any lower indenture items; or
- FSIs for the system and each subsystem and for some items at lower indenture levels.

A picture of the third alternative for a system having 5 functions would look like this:



[1] Remember, the use of the additional FSI Selection form is required only if you wish to analyze individual items at the equipment level, or below.

One function is unique to the system as a whole[1] and four are distributed among three subsystems. One function of subsystem 2 is unique to an equipment which has been selected as an FSI. A total of five FSIs have been identified, and all will be listed in the FSI Index.

E. FUNCTIONALLY SIGNIFICANT ITEMS INDEX (OPNAV 4790/118)

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

F. FAILURE MODES AND EFFECTS ANALYSIS (OPNAV 4790/119)

The Failure Modes and Effects Analysis (FMEA) provides the basic failure information required for applying the RCM decision logic for analyses. The FMEA identifies the specific conditions that are the dominant causes for functional failures -- the conditions that a PM task is intended to prevent or discover.[2] The FMEA is intended to identify dominant failure modes, those whose impact, either as individual or frequent events, requires consideration for preventive tasks.

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, not an academic, evaluation of failures. Active participation of users at this step in the analysis will have a major beneficial impact. Be sure to identify the dominant, real failure modes, not hypothetical modes that do not or are not likely to happen.[3]

---

[1] This is the level at which TSTP type-tests will usually be performed.

[2] This objective is not the same as that for the FMEA used by reliability analysts in the design process. However, if an FMEA complying with MIL-STD-1629 (SHIPS) has been previously prepared, it will be a valuable source of information.

[3] Some functional failures may have no dominant failure modes.

Each FSI in the FSI Index requires an FMEA.[1] Efficient preparation of the FMEA's requires a "bottom up" approach in which the lowest level FSIs are analyzed first, followed by the associated subsystem and system level FSIs. Identify failure modes at the lowest FSI level at which they can be perceived. Do not repeat these at higher indenture levels.

G. HIDDEN FUNCTIONS ANALYSIS (OPNAV 4790/127)

A hidden function is a function not apparent during normal operations. It may be a back-up mode that is manually or automatically selected when the primary source of the function fails, or it may be a warning or protective function that is activated by a temperature, pressure, or vibration sensor.

The Hidden Functions Analysis identifies these functions and determines whether they are covered by existing PM tasks.

H. DECISION LOGIC TREE ANALYSIS (OPNAV 4790/120)

The process for identifying applicable and effective tasks uses a decision logic tree. A decision logic tree uses a group of sequential yes/no questions to classify or characterize "something." This something may be a thing, a fact, or an event. In this application, it is an event, a functional failure. The answers to these questions will ultimately tell us about this failure's criticality (which may be different for each failure mode) and whether there is an applicable and effective maintenance task that will control it. The decision logic tree for doing what we have in mind is shown in Figure V-2. Note that the first three questions determine classification while the remaining questions deal with the search for applicable and effective tasks or with an alternative action, changing the design of the hardware.

Applying this logic will identify what, if any, preventive maintenance task(s) should be performed. Unavailability of safety-critical on-line functions or expectation of safety-critical failures requires either a task or specific acceptance of the alternative risks. If availability of non-safety-critical on-line functions or non-safety-critical failures are affected,

---

[1] If all functional failures are, in fact, completely considered at lower indenture levels, the FMEA should simply state that fact, and the remainder of the form should be left blank.

economic trade-offs determine task desirability. (On-line failures directly affecting operations are treated separately from those of support functions because of their higher level of impact.)

Off-line functions are considered separately. They are of two kinds -- hidden functions that protect the ship from multiple failures[1] and military mission functions not used frequently enough to provide confidence that they will be available when required. Either preventive or failure-finding tasks are required, when necessary, to ensure acceptable availabilities of these functions.

Since the quality of the results of applying the decision logic depends considerably on the understanding of each of the questions in the tree, let's review each question in some detail.

1. **Is the occurence of a failure evident to the operating crew while it is performing its normal duties?**
   This question divides functional failures into two groups:
   - Those that reveal themselves to the crew during their normal day-to-day activities (on-line functions). (Be sure you know exactly how this can occur.)
   - Those that are discovered when operation of infrequently-used equipment is attempted or when protective or back-up systems fail to operate when needed (off-line functions).

2. **Does the failure cause a loss of function or secondary damage that has a direct and adverse effect on operating safety?**
   This question divides on-line functional failures into two groups:
   - Those that directly impact operating safety. 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, not improbable combinations of events that have minor impact or are unlikely.

<u>If you are developing an initial program for a new ship, you will have to determine the impact of failures by reviewing drawings, specifications, and experience with similar designs. If there is already considerable in-service experience, be sure that you examine this experience to see whether safety has, in fact, been affected by this failure.</u>

[1] Either loss of redundancy or unavailability of a protection system, for example.

- Those that do not impact operating safety as described above. These failures have economic impact in the sense that failure deprives the user of a function that has value to him.

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:
   - Those that directly impact operations. These failures affect the ability of the ship to perform its function as a ship, including any military functions in regular, frequent use; and
   - Those that impact support functions in regular, frequent use.

4,5,6,7. Is there an applicable and effective preventive maintenance task or combination of task(s) that will prevent functional failures?
   Do not limit your answer by consideration of the maintenance level at which these tasks will be done. This question applies to all functional failures irrespective of their repair level and separates them into two groups:
   - Those for which an effective and applicable preventive maintenance task (or tasks) can be specified. Applicable means the task has the desired effect (really prevents or reduces the impact of functional failures). Effective, for safety-related failures, means that risk is reduced to an acceptable level, and, for other than critical safety failures, that the task is cost-effective. Each task, will be either a time-directed task, (life limit (LL) or rework/overhaul (RW) task), or a condition-directed task (CD), for example, a periodic check against some measurable standard.

     -- Time-directed tasks (RW or LL) can be applicable only if the probability of failure[1] increases with time. This time can be measured many different ways--some easy, some very difficult. Whatever the basis for time measurement, its relationship to failure probability must be as described above if the task is to be effective and time measure selected is to be practicable.

---

[1] More precisely, the hazard rate or conditional probability of failure.

-- Condition-directed tasks (CD) can be effective only if they efficiently convert functional failures to potential failures. Their effectiveness usually depends on their ability to eliminate a high percentage of functional failures at a low cost per task.

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

8. **Can redesign change criticality class?**
This question addresses the problem of safety-related functional failures for which there is no applicable and effective preventive maintenance task. Avoid the temptation to specify an ineffective task or collection of tasks. Address the practicability of changing the design in order to avoid these failures. If redesign is impracticable, then specifically identify the associated risk. (See Section J.)

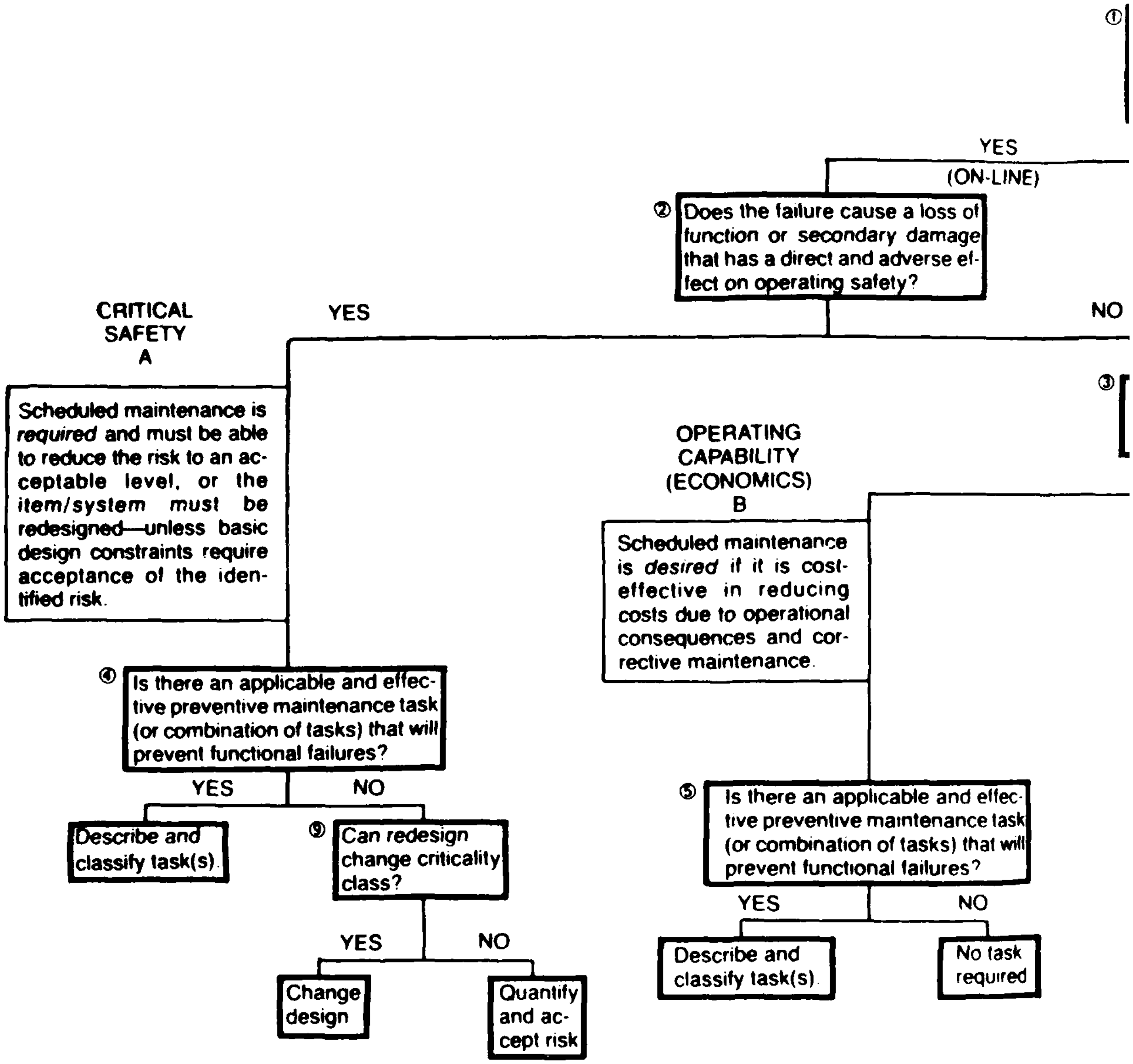
9. **Is a scheduled functional failure-finding task justified?**
This question determines the need for a failure-finding task (FF). These tasks are not preventive, but they are intended to discover failures that are otherwise hidden from the user. Occasionally, a hidden function provided by the design is either so reliable or the function is so trivial that no task can be justified.

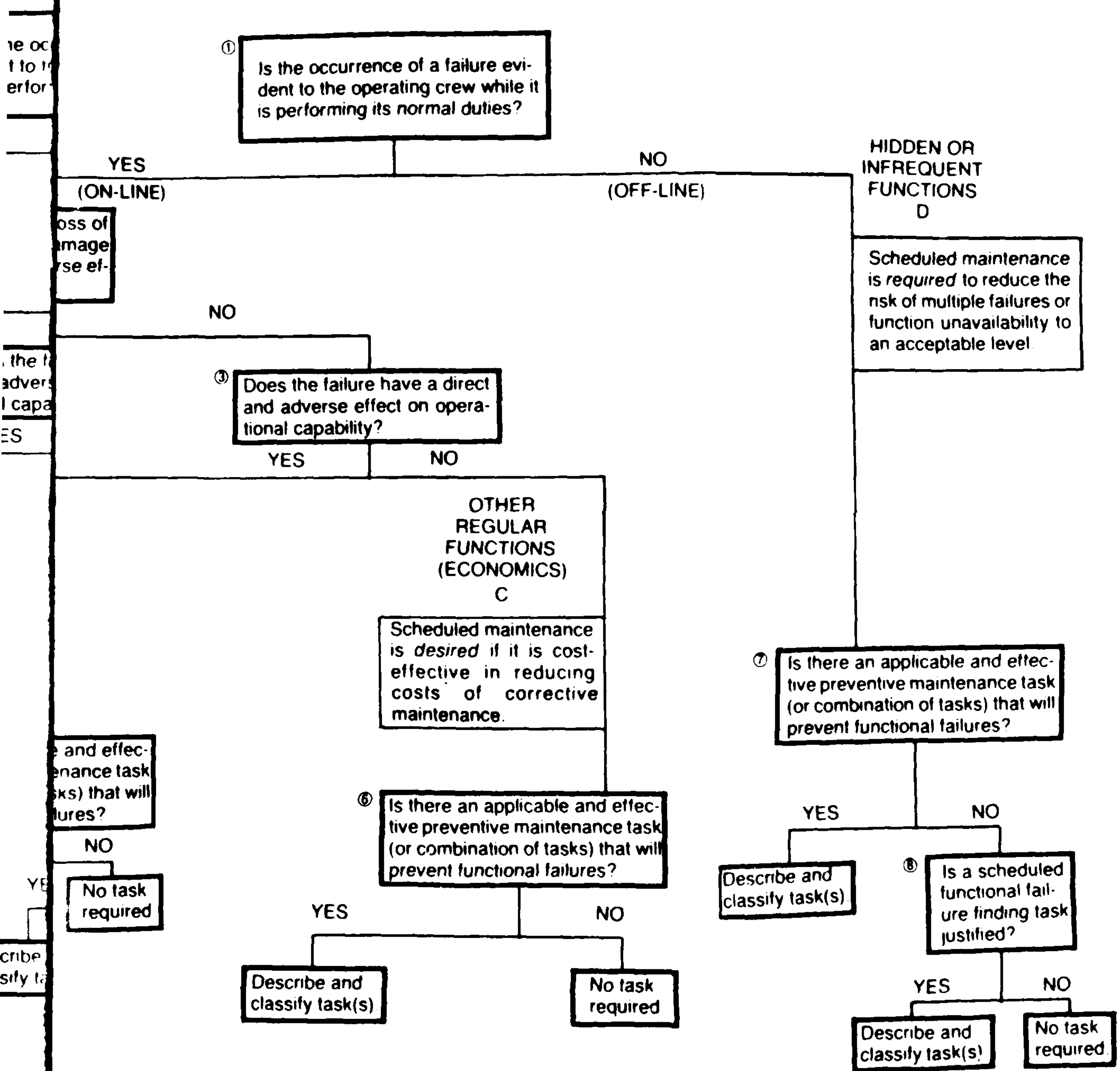
I. SERVICING AND LUBRICATION ANALYSIS (OPNAV 4790/121)

Servicing and lubrication are, of course, preventive maintenance tasks. (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 and, in fact, you may have established some. Since it is important that tasks of this kind not be overlooked (as they may be because they are often taken for granted), this analysis takes an overall look at servicing and lubrication requirements. It is based on review of existing requirements, either in PMS for existing ships or manufacturers' recommendations for new ships and equipment. Focus on minimum requirements. Keep in mind that manufacturers' recommendations tend to be excessive. Don't overkill because you doubt that the user will do what you require. Remember that the job will more likely be done if you specify common materials and sensible periodicities.

FIGURE V-2

THE RCM DECISION LOGIC TREE




①
Is the occurrence of a failure evident to the operating crew while it is performing its normal duties?
YES
(ON-LINE)
NO
(OFF-LINE)
HIDDEN OR INFREQUENT FUNCTIONS
D
Scheduled maintenance is *required* to reduce the risk of multiple failures or function unavailability to an acceptable level
NO
③
Does the failure have a direct and adverse effect on operational capability?
YES
NO
OTHER REGULAR FUNCTIONS (ECONOMICS)
C
Scheduled maintenance is *desired* if it is cost-effective in reducing costs of corrective maintenance.
⑦
Is there an applicable and effective preventive maintenance task (or combination of tasks) that will prevent functional failures?
YES
NO
Describe and classify task(s)
⑧
Is a scheduled functional failure finding task justified?
YES
NO
Describe and classify task(s)
No task required
NO
No task required
⑥
Is there an applicable and effective preventive maintenance task (or combination of tasks) that will prevent functional failures?
YES
NO
Describe and classify task(s)
No task required

J. SAFETY-RELATED DESIGN CHANGE RECOMMENDATION (OPNAV 4790/122)

The Decision Logic Tree recognizes that there will be instances when a functional failure has a direct, adverse impact on safety and there is no highly effective preventive task. The Safety-Related Design Change form provides a means for documenting your recommendations, if this situation occurs. Note that you should restrict these recommendations to safety-related failures. Do not use this form to address a non-safety-related design improvement.

APPENDIX A
GLOSSARY

ACTIVE FUNCTION	A function requiring some specific action of a hardware element.
APPLICABLE TASK	A task that reduces the impact or occurrence of failure.
COMMON CAUSE FAILURES	Failures resulting from the same casual event.
CO-FUNCTION	A function unrelated to another function that is provided "in parallel" by the same unit.
CONDITION-DIRECTED TASK	A task that compares condition or performance with a specific standard.
COST-EFFECTIVE	An efficient user of resources.
DECISION TREE	A structured sequential decision process, usually consisting of a series of binary questions.
DOMINANT FAILURE MODE	A failure mode that is important either as an event or because of its frequent occurrence.
EFFECTIVE TASK	A task that is worth doing.
FAILURE	An unsatisfactory condition.
FAILURE EFFECT	The end effect of a specific failure.
FAILURE-FINDING TASK	A task that discovers a hidden failure.
FAILURE MODE	The specific condition causing a functional failure (often best described by the condition after failure).
FUNCTION	A capability of a hardware element that is a specific requirement of its design.
FUNCTIONAL FAILURE	Loss of a function or degradation below the operationally required performance level.

HIDDEN FUNCTION	A function not apparent to the user during normal operation.
INDEPENDENT FAILURE	A failure not related to any other failure.
INHERENT RELIABILITY	The reliability that is characteristic of the design.
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	A failure defined by test or inspection criteria rather than by operational performance.
PREVENTIVE MAINTENANCE	Scheduled, periodic action intended either to prevent or discover failures.
PRIMARY FUNCTION	The most important function.
REDUNDANCY	System capacity in excess of requirements that avoids loss of function as the result of item failure.
RELIABILITY-CENTERED	Focused on maintaining inherent reliability.
SAFETY	Protection from threats to life or limb.
SECONDARY FUNCTION	Not the primary function.
TIME-DIRECTED TASK	A task performed solely on the basis of time (or a cumulative number of events) since some previous action.

APPENDIX B
PLANNED MAINTENANCE SYSTEM DEVELOPMENT FORMS

The forms illustrated in this appendix will guide the analyst in performing an RCM-based systems study as described in Section IV.

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

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

Figure B-1

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 SOURCES OF INFORMATION					
9 DESCRIPTION (Add additional sheet, if necessary)					
10 FUNCTIONS AND OUT INTERFACES					
11 SYSTEM IN INTERFACES					
12 FUNCTIONAL FAILURES				13 SERIAL NUMBER	

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

Figure B-2

1 SWAB NUMBER	2 NOMENCLATURE FSI CANDIDATE	3 SHIP CLASS	SH OF

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

8 DESCRIPTION	9 LOCATION	10 QTY

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

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

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

Figure B-3

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 SWAB NUMBER	9 NOMENCLATURE	10 LOCATION
		11 SERIAL NUMBER

FUNCTIONALLY SIGNIFICANT ITEMS INDEX
OPNAV 4790 118 (ED 2 82)

Figure B-4

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 4790/119 (ED 2 82)

Figure B-5

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 RECOMMENDED Y/N	14 TASK DESCRIPTIONS	15 PERIODICITY
								16 SERIAL NUMBER	

LOGIC TREE ANALYSIS
OPNAV 4790/120 (ED 10-83)

Figure B-6

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 (FD 2 82)

Figure B-7

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

MAINTENANCE REQUIREMENT INDEX
OPNAV 4790/123 (ED 2-82)

Figure B-8

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 SYMBOL	TIME	ANALYZE: WHAT WHERE WHEN HOW WHY	IMPROVED METHOD: ELIMINATE SIMPLIFY COMBINE CHANGE SEQUENCE	○ OP ☐ INSP SYMBOL	TIME	TOOLS PARTS MATERIALS TEST EQUIPMENT	WARNINGS CAUTIONS NOTES	RELATED MAINTENANCE	NO OF MEN AND RATE

PROCEDURE EVALUATION SHEET
OPNAV 4790/130 (ED 2 82)

Figure B-9

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 EQUIPMENT SWAB/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)

Figure B-10

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 4700/120 (F - 2 82)

Figure B-11

SHIP SYSTEM	SUBSYSTEM	MRC CODE	
SYSTEM	EQUIPMENT	RATES	M/H
MAINTENANCE REQUIREMENT DESCRIPTION		TOTAL M/H	
		ELAPSED TIME	
		PAGE OF	
LOCATION		DATE	

MAINTENANCE REQUIREMENT CARD (MRC)
OPNAV 4790/82 (REV 2-82)

Figure B-12

SHIP SYSTEM, SYSTEM, SUBSYSTEM, OR EQUIPMENT	REFERENCE PUBLICATIONS	DATE

CONFIGURATION

TEST	OTHER	SYSCOM MRC CONTROL NO	MAINTENANCE REQUIREMENT DESCRIPTION	PERIODICITY CODE	RATES	MAN HOURS	RELATED MAINTENANCE

MAINTENANCE INDEX PAGE (MIP)
OPNAV 4790/84 (REV 2-82)

PAGE OF

SYSCOM MIP CONTROL NUMBER

Figure B-13

1 DEVELOPMENT GROUP	2 SHIP CLASS	3 DEVELOPER	4 CONTRACT NUMBER	5 REVISION	6 DATE	SH OF

PHASE 1 FORM 114 SERIAL	PHASE 2 FORM 116 SERIAL	PHASE 3 FORM 117 SERIAL	FORM 118 SERIAL	PHASE 4 FORM 119 SERIAL	PHASE 5 FORM 120 SERIAL	PHASE 6 FORM 121 SERIAL	PHASE 7 FORM 123 SERIAL	PHASE 9 FORM 124 SERIAL	PHASE 12 SYSCOM MRC CONTROL NO	SYSCOM MIP CONTROL NUMBER
									7 SERIAL NUMBER	

RCM DOCUMENTATION CONTROL SHEET
OPNAV 4790/125 (E.O 10-83)

Figure B-14