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RELIABILITY CENTERED MAINTENANCE

by

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MAJOR, UNITED STATES MARINE CORPS

A paper submitted to the faculty of the Naval War College in partial satisfaction of the requirements of the Department of Operations.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

Signature: R.E. Love

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This paper addresses the requirement for Reliability Centered Maintenance (RCM) in fielded weapon systems. While Reliability Centered Maintenance is incorporated into developing weapon systems through the Logistics Support Analysis process it is not fully utilized in the post production process. Systems fielded with the benefit of Reliability Centered Maintenance are not routinely revisited to ensure that the inherent reliability of the system is being achieved. Preventive maintenance tasks are modified primarily as a result of user response and not through the integrated use of usage data and viable engineering analysis. The use of Reliability Centered Maintenance as an alternative maintenance strategy, service wide, is recommended to ensure that the inherent reliability of a weapon system is realized at minimum cost.

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ABSTRACT

This paper addresses the requirement for Reliability Centered Maintenance (RCM) in fielded weapon systems. While RCM is incorporated into developing weapon systems through the Logistics Support Analysis (LSA) process, it is not fully utilized in the post production process. Systems fielded with the benefit of RCM are not routinely revisited to ensure that the inherent reliability is being achieved. Preventive maintenance tasks are modified, primarily as a result of user response and not through the integrated use of usage data and viable engineering analysis. The use of Reliability Centered Maintenance as an alternative maintenance strategy, service wide, is recommended to ensure that the inherent reliability of a weapon system is realized at minimum cost.

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CHAPTER I

INTRODUCTION

> "The limitation imposed upon operations by logistics represents the final limit of a commander's plan of action."
>
> Sound Military Decision, 1942

The traditional approach to performing preventive maintenance is to acknowledge the relationship between the age of a particular item and its life expectancy. Historically, this meant that at a certain point in the life of an item it would be rebuilt or replaced regardless of its actual condition. Maintenance was performed on a time directed criteria (e.g. bimonthly, annually etc.). A significant amount of time and effort would be expended bringing the item into a maintenance facility, taking the appropriate action, and returning the asset to service. An additional cost could be attributed to the loss of the operational availability of the item during the period of servicing. This paper will present the Reliability Centered Maintenance concept as an alternative maintenance strategy for developing and or refining preventive maintenance tasks and schedules.

The concept of Reliability Centered Maintenance evolved as an alternative to the traditional approach in an effort to restore the inherent reliability of a system at the minimum cost. Reliability Centered Maintenance is used by all services in the Logistics Support Analysis (LSA) process. While LSA and Reliability Centered Maintenance serve as a fundamental requirement in systems design and development, the Reliability Centered Maintenance concept has not been accepted into the post production phase of a weapon systems life. Although current directives require its use, Reliability Centered Maintenance has not been accepted for refinement or development of preventive maintenance tasks in the post production phase of a weapon systems life cycle.

The reader is presented with sufficient information to understand the Reliability Centered Maintenance program, appreciate its´ capabilities and potential value added to applicable weapon systems. Chapter II of this paper reviews the historical basis for the Reliability Centered Maintenance program. Chapter III provides the reader with an overview of the underlying concept behind Reliability Centered Maintenance, to include a discussion of preventive maintenance and failure analysis. Chapter IV describes the principle methodologies involved in the process. Chapter V is a discussion of post production application of Reliability Centered Maintenance based on the preceding chapters. Conclusions are presented in the last chapter and suggest that Reliability Centered Maintenance is a viable maintenance strategy for post production weapon systems.

CHAPTER II

HISTORICAL PERSPECTIVE

In 1968 the Federal Aviation Administration (FAA) expressed a desire to utilize a new concept in the initial maintenance program for the Boeing 747. This concept, later to be known as the Management Steering Group-1 (MSG-1), was integrated into the design of the Boeing Maintenance Plan. The plan was further refined by the Air Transport Association in 1970 and re-published as Management Steering Group-2. The objective of MSG-1 and MSG-2 was to develop a scheduled maintenance program to maximize safety and reliability at the lowest cost. MSG-2 was applied to the development of the DC-10 aircraft. A comparison of scheduled maintenance actions (overhaul) was conducted between the DC-10 and the DC-8. The DC-8 had been developed using the traditional approach while the DC-10 had the benefit of Reliability Centered Maintenance. Overall Reliability Centered Maintenance contributed to the reduction of 332 items as candidates for maintenance (from 339 to 7). Elimination of the requirement to conduct overhaul actions not only resulted in the reduction of labor and material costs, but decreased the replacement parts inventory by 50%.[1]

The Department of Defense Directive 4151.16, "DOD Equipment Maintenance Program" was the first DOD directive requiring the Services to use Reliability Centered Maintenance. Prior to this time Reliability Centered Maintenance guidance had been included in Program Guidance Memoranda. Under the Program Guidance each Service was able to implement Reliability Centered Maintenance using its own unique policies and procedures. The DOD Directive addresses the applications of the Reliability Centered Maintenance Program to preventive maintenance program development and execution.

CHAPTER III

RELIABILITY CENTERED MAINTENANCE

OVERVIEW

Reliability Centered Maintenance is used to develop the minimum preventive maintenance tasks necessary to ensure that an equipment item or weapon system meets its inherent reliability requirement at minimum cost. The concept provides a means to address basic questions central to the development of applicable and effective maintenance plans.

The objective is to design a preventive maintenance program by evaluating the maintenance for an item according to anticipated failures and their consequences. The Failure, Modes Effects and Criticality Analysis (FMECA) is a major input into the Reliability Centered Maintenance analysis.[2]

One of the basic purposes of preventive maintenance planning is to systematically anticipate those factors that could impact on the reliability and maintainability of a weapon system. Reliability Centered Maintenance identifies specific tasks to prevent or reduce the probability of failure (risk) to an acceptable degree. Preventive maintenance, in this context, is concerned with preventing wear out type failures.

If the critical point can be identified immediately prior to failure and maintenance action taken, the opportunity for cost savings and greater efficiencies will result.

There are three major elements to the Reliability Centered Maintenance program. Equipment Design guidelines, preventive maintenance program development and continuing review and update of preventive maintenance requirements are three components of the Reliability Centered Maintenance Program.[3] Only the latter two are considered in the context of this paper, and are incorporated into the discussion which follows. Equipment design guidelines are primarily related to the system development phase.

CONCEPT

The Reliability Centered Maintenance Program consists of an analysis of the components of a weapon system. The system is broken down into a work breakdown structure (WBS) for ease of analysis. Each component is then analyzed, using the FMECA (if available) to determine the ways the particular item can fail and the associated consequences. Each failure is then categorized as having an operational, safety, or economic consequence. Additionally, a failure is determined to be hidden or identifiable to the operating crew. Based on these categories, the item and its associated failure are passed through a decision logic process which, when properly applied, will lead an analyst through to an applicable and effective preventive maintenance task.

The tasks are then packaged to economize maintenance actions. In those cases where no applicable or effective task is determined the decision logic will lead the analyst to the conclusion that the item should be either redesigned or operated to failure (corrective maintenance).

PREVENTIVE MAINTENANCE

The whole idea behind preventive maintenance is to identify a potential failure, take a specific maintenance action to reduce the probability of occurrence to an acceptable degree and return the item to service. Preventive maintenance is primarily concerned with preventing wear out type failures. The analyst develops specific tasks which can be scheduled to be performed as close to the anticipated wear out time as possible. The goal is to obtain increased operational availability of the item at minimum cost.[4] The alternative to preventive maintenance is corrective maintenance. Corrective maintenance is performed *after* the failure has occurred whereas preventive maintenance is performed *before* the anticipated actual failure.

Preventive maintenance tasks are initially determined during system development based on engineering analysis. These tasks are assigned using a variety of statistical techniques based on similar systems, maintainability and reliability tests. Actual usage data is minimal. Normally, the analyst will develop tasks in a very conservative manner. Tasks will be assigned rather than omitted to reduce the opportunity for error. The result is a maintenance plan that may have too much preventive maintenance designed into the system. Tasks are routinely corrected after the system has been fielded and actual usage data is developed. Maintenance personnel provide feedback in accordance with each Services standing operating procedures.

There are four generic preventive maintenance tasks used in Reliability Centered Maintenance analysis. Each task is assigned based on the Reliability Centered Maintenance decision logic and the unique component failure. The four tasks are:[5]

> Scheduled <u>inspection</u> of an item at regular intervals to find any potential failures.
>
> Scheduled <u>rework</u> of an item at or before some specified age limit.
>
> Scheduled <u>discard</u> of an item at or before some specified life limit.
>
> Scheduled <u>inspection</u> of a <u>hidden function</u> item to find any functional failures.

In those cases where an inspection is required the goal is to determine whether or not certain criteria are met. If the item exceeds the criteria, then a task is applicable.

FAILURE ANALYSIS

Most equipment items are subject to performance degradation and eventual catastrophic failure. When a particular item no longer can perform its stated mission, it has failed. Traditionally, preventive maintenance tasks were developed based on a particular age limit. Emphasis was on determining the age at which an item would fail as opposed to the ways the item failed. However, Reliability Centered Maintenance recognizes that failures can occur not so much because the item is old but perhaps because it has been used more or less frequently than anticipated. Reliability Centered Maintenance attempts to focus on the reason(s) for failure, the consequences of failure, and the benefits of performing a preventive maintenance task.

Reliability Centered Maintenance identifies two types of failures; functional and potential. Once identified each failure is classified according to its severity and consequence. The inability of an item to perform its mission would be considered a functional failure. A quantifiable symptom which indicates that a failure is imminent would be classified a potential failure.

Having identified a failure or potential failure the condition is categorized as one of the following:[6]

Catastrophic: A failure which may cause death or weapon system loss.

Critical: A failure which may cause severe injury, major property loss, or major system damage which will result in mission loss.

Marginal: A failure which may cause minor injury, property damage or minor system damage which will result in delay, loss of availability or mission degradation.

Minor: A failure not serious enough to cause injury, property damage or system damage, but which will result in unscheduled maintenance repair (corrective maintenance).

Once the failure or potential failure condition is identified and classified, the analyst will qualitatively determine the consequence of the failure. As a result of the consequence the appropriate task, if any, will be determined. Consequences may be safety oriented, operational (degradation of mission attainment capability), economic (cost of repair), or hidden. The last consequence simply indicates that a failure is not evident to the operating crew and may lead to multiple failures. The failure itself may have no direct impact on operating capability.

FAILURE MODES EFFECTS AND CRITICALITY ANALYSIS

The Failure Modes Effects and Criticality Analysis (FMECA) is an effective tool in the design phase of system development. It is a methodology to identify possible system failures, the causes of these failures, the effects of failure on the system and the criticality in terms of safety and mission accomplishment. The FMECA is employed to evaluate system design in terms of equipment interface, application, stress, in regards to operational modes.

The object is to identify weaknesses and the criticality of each. It is a "bottom up" approach, whereby the failure is analyzed at the component level and traced up to the effect on the system as a whole.[7] The FMECA should not be confused with Fault Tree Analysis which is a "top down" approach. In Fault Tree Analysis the system failure is considered and an attempt is made at identifying failures down to the source or sources.

CHAPTER IV

RELIABILITY CENTERED MAINTENANCE

PROCESS

What follows is not intended to be a detailed description of the Reliability Centered Maintenance process, but rather, a summary description to emphasize the benefits of Reliability Centered Maintenance and the opportunity cost of not using it in fielded weapon systems.

The process of evaluating failure consequences and developing maintenance tasks is developed by using a wiring diagram. This diagram is called the Reliability Centered Maintenance decision logic. Inherent to the decision logic is a number of priorities based on the particular area and its importance. Each level within the logic is tailored to channel the analyst towards a final recommendation for the development of the minimum preventive maintenance tasks required for safety and operations.

The first step in the Reliability Centered Maintenance process is to identify significant items. This is accomplished by pruning the work break down structure of those items which would not have a severe impact on operating safety or have major economic consequences. A simple example of a tank will clarify the distinction. The traversing mechanism on the turret is a high dollar value item and its failure could cause loss of mission and safety concerns. It would be classified as significant item. The small safety light in the coppola, on the other hand is inexpensive and its failure alone would not adversely impact operating safety, hence it would not be considered in the analysis. After all significant items have been identified the Reliability Centered Maintenance analysis will have reduced the weapon system to its major components and structured the system into a logical organization for analysis. What remains is a foundation which is most likely to benefit from Reliability Centered Maintenance.

The second step in the process is to evaluate the failure consequences of each of the significant items remaining. Each item must be scrutinized to determine its functions and failure modes. In some cases the failure of the item is not immediately apparent to the operating crew and will be classified as a hidden failure. These hidden failures will be handled separate from the obvious ones. Apparent failures will be divided into three categories based on their consequences; operating safety, operational, and economic. Operational and operating safety consequences are considered as having an immediate impact while hidden and economic consequences will be delayed. At this point we have already identified significant items, whether or not the failure is obvious to the crew and what the consequences of their failure may be. The following step requires the analyst to consider each failure mode to determine whether or not the item is compatible with one of the four preventive maintenance tasks identified in Chapter III, Preventive Maintenance. The following questions must be answered in order, for each item, by the analyst;

> Is an on-condition task to detect potential failures both applicable and effective? If not,
>
> Is a rework task to reduce the failure rate both applicable and effective? If not,
>
> Is a discard task to avoid failures or reduce the failure rate both applicable and effective? If not, do not perform scheduled maintenance. Either operate to failure (and perform corrective maintenance) or consider redesigning the item.

At this point age exploration tasks may be applied.

AGE EXPLORATION

Age exploration is nothing more than exploring the failure resistance for a component. As the item is used it becomes more susceptible to failure. During design development little is known about failure resistance unless a like item exists or if extensive testing is conducted. Initial engineering data is recorded on the Logistics Support Analysis Record (LSAR). In the case of a fielded weapon system each service operates a maintenance data collection system. Rather than await a response from a maintenance specialist the Inventory Control Point (ICP) having responsibility for the weapon system can monitor failures. Actual usage data in realistic operating environments can provide viable data in the refinement of preventive maintenance tasks and intervals.

By reviewing the resistance to failure and time to actual failure an analyst can determine the optimum time for a particular on condition task. If, for example, historical data indicates that tires on a High Mobility Multipurpose Wheeled Vehicle (HMMWV) experience blow outs at 60,000 miles and exhibit cracks at 45,000 miles, an on condition task can be developed at 45,000 miles. If a tire shows cracks, then it may be replaced. If however no cracks are visible then an inspection task may be necessary every 5,000 miles. These time limits may be grossly different from the initial tasks resident in the Logistics Support Analysis Record. By comparing actual data we can correct the original engineering analysis, restore any lost reliability and improve operational availability.

PACKAGING OF MAINTENANCE TASKS

Once each maintenance task is developed a frequency or interval must be assigned. Should we perform a lubrication task semi-annually, every 3,000 miles or 200 operating hours? Should the task be performed both semi-annually and every 3,000 miles? These are questions that are difficult to answer without the benefit of usage data. The analyst uses Age Exploration as one method of determining frequency. Once developed should each item have to be broken down and have maintenance performed on it without regard to the other component maintenance intervals? Surely the answer is that we must consider all component maintenance intervals when assigning frequency of maintenance. If an aircraft turbine engine requires maintenance every 150 operating hours and a component requires maintenance every 155 operating hours both can be accomplished concurrently. This concurrent maintenance would be a packaging task. Packaging tasks result in some tasks being performed more frequently. The additional cost is more than outweighed by the increased maintenance efficiency. Those tasks that are most expensive, both in terms of actual cost and in terms of down time will shape the overall program.[8]

CHAPTER V

POST PRODUCTION APPLICATION

RELIABILITY

Reliability Centered Maintenance is used to develop a preventive maintenance program based on the design of the equipment. Each equipment item has a reliability intrinsic to its design. Maintenance actions cannot improve upon the inherent reliability of a weapon system.[10] Reliability Centered Maintenance studies the failure characteristics of the components of a weapon system to determine effective scheduled maintenance tasks and intervals to maintain or restore the reliability of the system.

What is the importance of reliability to the operational or tactical commander? Is it of any worth to study reliability? Why not simply field the weapon system and develop plans without regard to this thing called "reliability"? In order to understand the importance of reliability it is necessary to define it. Professor Benjamin S. Blanchard best defines reliability as,

> "...the probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating conditions.".[9]

Consider the commander of a carrier battle group. He develops plans for the effective utilization of his force with the implied understanding that his ships and supporting assets will function when called upon to do so. If, however, his aircraft were designed with an inherent reliability of 50% and only when operating under clement weather conditions, the commander may be in for a rude awakening. Consider further that improper preventive (scheduled) maintenance tasks are performed and that only 40% reliability is being achieved. In other words the system is experiencing a 10% degradation in reliability attributable to lack of scheduled maintenance. How many aircraft will be operationally available when called upon to function, and will they remain operational for the duration of the exercise? The implications are enormous. Imagine the surprise of General Eisenhower in June 1944 if he were told that he could not conduct the Normandy invasion because the probability of the assault ships successfully crossing the channel was only 40%, and then only in ideal weather! The commander, at any level, expects that his equipment will function when called upon and will continue to function for the duration of the mission.

FIELDED EQUIPMENT

Fielded equipment is considered to be those items now in the hands of the operational forces or in storage awaiting issue, rebuild, or serving as contingency stock. Fielded equipment can be broken down into two generic categories for the purposes of this paper. The first category consists of those items of equipment that were developed with the benefit of Reliability

Centered Maintenance. Preventive maintenance is being performed based on the engineering analysis of systems, primarily without usage data. The second category consists of those items that were fielded without the benefit of Reliability Centered Maintenance. These items could have been procured before the Reliability Centered Maintenance program was implemented, items that were excluded from the program or Non-Developmental Items (off the shelf, e.g. John Deere tractors).

In the latter case equipment items may be excluded from the Reliability Centered Maintenance program because they could not benefit from it. For example, electronics equipment are routinely excluded from analysis. Electronics tend to perform at an acceptable level without indication of a potential failure. By using an extensive burn in period manufacturers can identify early system failures before fielding.[10] The usual preventive maintenance is to replace the item after a given period of time or after a predetermined operational period (e.g. 100 hours of actual use). The full application of the Reliability Centered Maintenance program is intended for complex mechanical systems. In some cases the process may not be economically feasible when considering the cost of the item and the potential benefits to be gained.

In either case after a new item has been fielded its preventive maintenance program must be reviewed to validate maintenance task intervals. Too much maintenance results in reduced operational availability, higher maintenance labor and materiel costs, and ineffectual utilization of personnel and equipment. Insufficient maintenance can result in a greater amount of operational, and safety failures, as well as an unrealized system reliability capability.

By applying Reliability Centered Maintenance to selected fielded weapon systems the inherent reliability of the system can be restored. By examining how a maintenance plan was developed, and comparing it to actual usage data, tasks can be refined and or corrected. Age exploration tasks can validate potential failure frequencies and characteristics. The results of which can be used to adjust preventive maintenance intervals. The Failure Modes Effects and Criticality Analysis provides a structured method for analyzing each functional failure and in determining the appropriate task. Several studies of individual weapon systems have been conducted within the services regarding the feasibility of Reliability Centered Maintenance for fielded systems. The United States Marine Corps has taken the lead in the development of integrated user friendly software and analysis techniques. Their latest analysis, the Light Armored Vehicle (LAV-25), reflects not only the Marine Corps´ dedication to the Reliability Centered Maintenance program, but the potential savings that *could* be achieved. The LAV series of vehicles was produced by the Canadians and purchased, with modification, by the United States. The Marine Corps has identified a significant reduction of preventive maintenance tasks and associated task intervals for the

LAV-25.[11] In addition, a number of collateral benefits were identified in the development of a software package to facilitate the analysis. The software provides the analyst with the capability to access engineering data developed during the acquisition process with actual Marine Corps usage data for the entire population of LAV-25's. Using the latest technology in statistical analysis a number of tests are performed (e.g. La Place) to determine the optimum time to schedule rebuild for either the entire weapon system or for a particular serial numbered vehicle.

Presently, the services do not actively or routinely review the achieved reliability of a weapon system. Other indicators, such as readiness, are monitored by exception. In other words if a weapon system is not at the stated readiness level at a particular point in time then an analysis takes place and actions taken as appropriate. The process is time consuming and costly. Equipment readiness levels may remain low until the cause can be identified and corrective actions initiated. Combat efficiency can suffer during the time it takes to identify the deficiency, isolate the cause, initiate corrective action and monitor to ensure that the corrective action was effective. The use of Reliability Centered Maintenance can identify potential problems *before* they occur. It is a proactive approach to deal with maintenance issues early prior to system failure.

Significant cost savings can be realized and operational effectiveness enhanced, for example, in the retrograde and rebuild of major end items. Presently, major end items are returned to the Depot Level (5th echelon) repair facility at the end of a predetermined wear out age. Unfortunately, the particular item may not necessarily need a complete rebuild at that point in time. The item, none the less, is sent to the rebuild facility, broken down into its´ lowest component parts and rebuilt. The costs of performing this rebuild is great, considering transportation costs, holding costs of parts, maintenance labor costs, and operational loss due to the nonavailability of the weapon system. Reliability Centered Maintenance can be used to save time and money in three ways.

First, by monitoring the system preventive maintenance tasks can be refined to restore lost reliability. This will ensure that the system will operate when called upon to do so for the duration of the weapon systems life. Second, using various statistical tests (e.g. La Place) specific weapon systems can be identified as candidates for rebuild. Only those systems which are exhibiting wear out characteristics would be retrograded, based on actual system failure data. Third, rather than performing a a comprehensive rebuild on the system only specific components would be retrofit based on the Reliability Centered Maintenance logic.

In his thesis at the Naval Postgraduate School, LCdr. Harris examined the maintenance plan for the S-3A aircraft. The S-3A is a shipboard based anti-submarine warfare aircraft built by Lockheed Aircraft Corporation. It was built without the benefit of Reliability Centered Maintenance in the mid 1970's. LCdr. Harris proved that by applying the principles of Reliability Centered Maintenance selectively on the S-3A a significant improvement in maintenance *could* be realized by the U.S. Navy.[12]

The U.S. Army conducted a comprehensive test to assess a system's reliability after repairs had been completed. The Army Chemical Command Systems Analysis Office concluded that the analytical feasibility of computer models using reliability analysis should be performed.[13] They determined, through stochastic analysis that computer models could support decision making for determining the type of maintenance needed to be performed. Such analysis needed conducted with available heuristic analytical techniques to ensure the validity of the computer results. The model that was developed provided a mechanized method for the systematic analysis of hazard information and for updating the reliability assessments of weapon systems.

AUDITING

For the maintenance strategy to remain viable requires that an iterative evaluation be conducted over the life of the weapon system. Equipment modifications, redesign, revised operational considerations, and new uses for the system will impact on the original maintenance plan. Mechanized systems must be utilized to capture the wealth of usage data available after system fielding. Although all services maintain maintenance data collection systems, these systems are not directly interfaced with the Logistics Support Analysis Record. The Logistics Support Analysis Record is a data base for the engineering data used during systems development. Manual comparisons would be time and manpower intensive and detract from potential cost savings achieved by the Reliability Centered Maintenance program. Automated systems should be standardized to accommodate the electronic data interchange of information between services.

By auditing the operation of a weapon system we can determine the adequacy of the original preventive maintenance tasks and schedules. A determination can be made regarding the achieved reliability of the system and, if lacking, aide in the determination as to whether a Reliability Centered Maintenance analysis is appropriate.

CHAPTER VI

CONCLUSIONS

The Reliability Centered Maintenance program provides the services with a logical, efficient method for identifying deficiencies before they occur. Because the program is used in developing weapon systems, the transition to post production application would be relatively painless. The program can be selectively applied and used to monitor maintenance and equipment performance efficiently. Contractor engineering estimates will be monitored and refined to provide the operating forces the most reliable equipment available to accomplish their assigned tasks.

There are three conclusions that can be drawn from this study of the Reliability Centered Maintenance strategy. These conclusions are:

1. That Reliability Centered Maintenance is a formal, logical process which can be applied to post production weapon systems, service wide.

2. That Reliability Centered Maintenance is a viable maintenance strategy for selected weapon systems.

3. That the services must develop a systematic methodology for the development and refinement of preventive maintenance tasks

for those fielded weapon systems which could most benefit from Reliability Centered Maintenance.

This paper presented the Reliability Centered Maintenance program in a broad based perspective. It is in no way intended as a complete analysis of the program or its implementation. The problems of identifying weapon systems for inclusion in the program, development of specific auditing procedures, development of appropriate data collection and interface information systems needs to be addressed in applicable technical publications. Additionally, force structure modifications must be identified and implemented.

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