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GUIDANCE FOR DEPENDABILITY IN-SERVICE

Edition B, Version 1

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ALLIED DEPENDABILITY MANAGEMENT PUBLICATION

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NATO LETTER OF PROMULGATION

4 May 2022

1. The enclosed Allied Dependability Management Publication ADMP-02, Edition B, Version 1, GUIDANCE FOR DEPENDABILITY IN-SERVICE, which has been approved by the nations in the LIFE CYCLE MANAGEMENT GROUP (AC/327 LCMG) is promulgated herewith. The recommendation of nations to use this publication is recorded in STANREC 4174.

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Dimitrios SIGOULAKIS
Major General, GRC (A)
Director, NATO Standardization Office

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CHAPTER 1 INTRODUCTION

1.1. GENERAL

1. Dependability is a key characteristic of all items[1], having a direct impact on mission performance and thus mission success. The dependability characteristics of any item are inherent in its design, thus dependability should be considered from the very beginning of the pre-concept stage and be continued, in a disciplined manner, throughout the whole life cycle by the implementation of dependability disciplines as described in the IEC 60300 series standards referenced at Section 1.4 in this document.

2. Dependability is the collective term describing the continued and safe operation of any simple or complex item. The factors that influence the dependability performance of any item are reliability, maintainability, availability, testability, maintenance, and safety. In most items reliability and maintainability are the key performance characteristics of interest as they have a direct impact on mission success and life cycle cost. The logistic and maintenance strategy of the item are mainly external, but can have significant impact on its availability performance, as it reflects the ability to provide the necessary resources to implement optimized maintenance procedures developed and refined through the life cycle of the item.

3. When in-service, it is necessary to assure that the inherent levels of dependability capability as described in the requirements documents are achieved while in use. It is necessary as well to understand any impact of changes on Life Cycle Cost (LCC) while meeting operational commitment over the life of the item.

4. The primary challenges are:

   a. to be able to quickly identify and correct technical problems that cause levels of dependability performance to deteriorate relative to requirements; and

   b. to ensure dependability is appropriately factored into changes in design, support, operating environment and procedures that will arise over an item's life cycle.

5. This requires a continuous process of collecting data from operations and maintenance, analyzing the data to extract information about dependability performance, and when required, making decisions for sustaining dependability performance and optimizing life cycle cost. Depending on the provisions made for the in-service support, responsibility for conducting some or all of these activities may be contracted out. In cases where a certain level of dependability performance has been guaranteed, it is necessary to ensure that adequate knowledge and visibility of support activities is retained so as to minimize disputes over responsibility.

1.2. PURPOSE

The continuing assessment of in-service dependability performance is commercially and operationally important, and enables the cost effective management of defence materiel throughout its life cycle. The purpose of this document is to provide guidance on in-service dependability. To achieve this, the following actions should be performed:

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[1] Item includes systems, equipment, be it hardware or software based, and services.

a. monitoring in-service performance

b. collecting data

c. analyzing data

d. finding and taking action

1.3. APPLICABILITY

This document applies to dependability activities of all items procured for military use within NATO Nations when in-service. It should be used by all members of projects and in-service organizations, including the various NATO Agencies, who are responsible for dependability.

1.4. NORMATIVE REFERENCES

A. ADMP-01 (B) Guidance for Developing Dependability Requirements

B. ADMP-03 (A) Guidance for Classification and Analysis of Dependability Events

C. AAP-20 (C) NATO Programme Management Framework (NATO Life Cycle Model)

D. AAP-48 (B) NATO System Life Cycle Processes

E. ALP-10 Guidance on Integrated Logistics Support for Multinational Armament Programmes

F. ALCCP-01 NATO Guidance on Life Cycle Costs

G. IEC 60300-1:2014 Ed 3 Dependability management - Part 1: Guidance for management and application

H. IEC 60300-3-2:2004 Ed 2 Dependability Management Part 3-2: Application Guide - Collection of Dependability data from the field

I. IEC 60050-192:2015 Ed 1 International Electrotechnical Vocabulary – Part 192:Dependability

CHAPTER 2 CONCEPTS AND FACTORS

2.1. EVOLVING MAINTENANCE AND SUPPORT CONCEPTS

1. Since the early 2000s, Industry has become increasingly involved in the provision of support services during the in-service life of an item. Performance-based contracts have been implemented in which some or all support activities, including dependability activities, have been contracted out.

2. The primary objective of these performance-based contracts is to establish a minimum acceptable level of performance and support criteria for a particular item, and configure the support of it to achieve this performance at an optimum cost. These support contracts often link the acquisition contract with the long term support contract and may include incentives tied to performance.

3. Performance can be defined in terms of military objectives using the following criteria:

   a. Availability;

   b. Reliability;

   c. Cost Per Unit Usage;

   d. Logistics Support Footprint;

   e. Logistics Response Time.

2.2. FACTORS AFFECTING IN-SERVICE DEPENDABILITY

When in-service, a number of factors may affect dependability.

a. Age: Time can have a detrimental effect on dependability, since many materials degrade as they get older. This includes electronic as well as mechanical systems, but does not apply to software. Deterioration will occur whether an item is in use or not.

b. Use: The life of an item is very dependent on how it is used. This would have been defined in the usage or mission profile, which is referred to in NATO documents as the Life Cycle Environment Profile (LCEP) and is the term that will be used throughout the remainder of this document. Any changes to the LCEP will have an impact on dependability. Even without changing the original LCEP, all items have a finite life and will gradually deteriorate through the normal process of wear, for example, distance travelled, hours run or number of cycles. The effects of wear can be mitigated by preventive maintenance.

c. Abuse: The accidental, negligent or deliberate abuse of an item can have a significant effect on its dependability. Undue stresses caused by poor servicing, use outside the design envelope, operational damage and inappropriate transportation or handling, will accelerate deterioration and lead to premature failure. Although little can be done to overcome accidental or deliberate damage, negligence can be minimized through well managed servicing and storage, up to date documentation and sound training.

d. Repair: As an item gets older it may be subject to an increasing number of repairs. Every repair will have a small but tangible effect on its integrity, and hence its subsequent dependability. This is especially true of electronic circuit boards, which can only be repaired a finite number of times. At appropriate intervals, item replacement should be carried out.

e. Maintenance: Items that are maintained too often or not enough can induce a negative impact on dependability. It is therefore imperative to review the periodicity and effectiveness of the maintenance on a regular basis.

f. Obsolescence: All items become progressively obsolete as component parts and sub-assemblies are superseded or discontinued. This is especially true for electronics and COTS items.

g. Configuration: Most items with a long in-service life will be subject to successive modification programs, to improve performance or overcome safety and obsolescence issues. Unless this activity is strictly controlled, the modification state of individual items and spares within a large fleet will tend to differ. Since certain combinations of modifications could affect dependability, configuration management should always be performed.

h. Upgrades: Any form of upgrade or improvement program should be managed with care, since both hardware and software changes could affect dependability. The measurement of performance parameters before and after upgrade will be very important to verify successful implementation. Such opportunities should always be used to improve dependability where possible.

i. Major Damage: Major accidents and battle damage can affect the subsequent dependability of an item. Although an item may appear to be restored to full working order, over stresses, distortion and intermittent faults may well be overlooked. Examples might include heavy landings for aircraft, battle damages of vehicles and collisions for ships. Any item suffering significant damage should be clearly identified and treated as a special case when analyzing dependability data.

j. Training: Training for Users and Maintainers must keep pace with changes to item and procedures. External validation to ensure training remains up to date and effective should be carried out.

2.3. OTHER FACTORS TO BE CONSIDERED FOR IN-SERVICE DEPENDABILITY

The following factors should be considered as well:

a. Boundaries: Whatever the nature of an item and the extent of a performance-based contract, there will be an interface between the User and Supplier. The nature of this boundary may change between peacetime activities, operations and war. Serious consideration must be given to the functions carried out by the User and the Supplier on either side of the interface. If support is to be effective it is essential that these boundaries and responsibilities are clearly defined in the contract.

b. Dispute Resolution: If a performance-based contract is not fully inclusive, it may be necessary to review incidents, to determine whether rectification lies within the scope of the contract. Most are unlikely to be contentious; however, a proportion may need to be formally resolved under a dispute resolution process.

c. Partnership: However well written a performance-based contract may be, issues will inevitably arise which have not been foreseen. Therefore, a good working relationship, based on honesty and trust between User and Supplier is essential if difficulties are to be avoided or resolved by mutual consent.

d. Any item supported by an in-service performance-based contract should seek to sustain or enhance the levels of dependability achieved during development. Contracts should be flexible, with well-defined boundaries and include transition arrangements in case of termination or transfer.

CHAPTER 3 IN-SERVICE DEPENDABILITY

3.1. GENERAL

Managing in-service dependability requires the monitoring of performance through a continuous process of collecting data from operations and maintenance, analyzing the data to extract information about significant events and trends in dependability performance. The processed data is used to make decisions on optimizing the item or its support, taking action when required. It can be costly and time consuming to achieve this; however, failing to do so can be more costly and lead to a decrease in mission success and an increase in Life Cycle Cost. It is therefore essential that the objectives and processes are identified well in advance and arrangements made to meet them in an effective manner. These should be captured in an in-service dependability plan and implemented throughout the useful life of the item. The process for managing in-service dependability is shown in Figure 1.

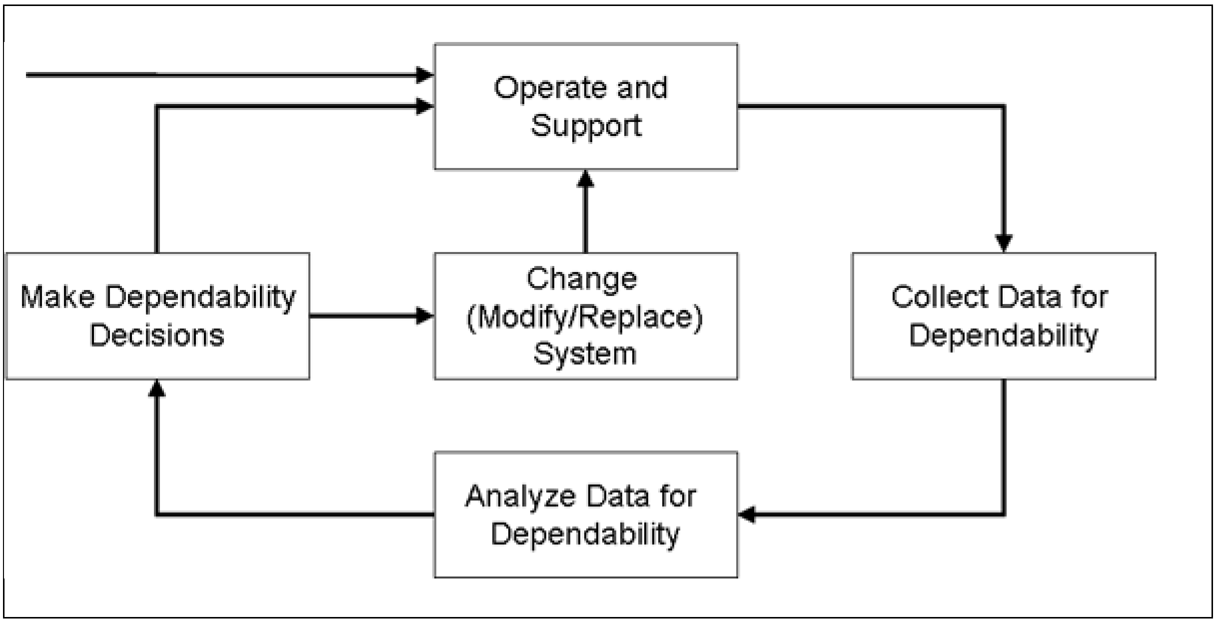

FIGURE 1: In-Service Dependability Management Process

3.2. MONITORING IN-SERVICE DEPENDABILITY

1. Monitoring in-service dependability begins with an appreciation of the range of dependability performance issues that are relevant to in-service materiel management. It is critical that the process for monitoring of dependability data is considered early during acquisition and designed into the item rather than reverse-engineering it when in-service.

2. The purpose of monitoring in-service dependability is to assess the adequacy of support processes on a continuous basis, so that areas of concern or potentially detrimental trends can be identified early. This permits action to be taken before problems begin to seriously impact operations and/or expenditures. Effective parameters such as output/capacity, availability, reliability, spares and operating & maintenance cost are all candidates for performance monitoring.

3. The performance monitoring philosophy makes use of standard data sources already available for other purposes and taps into them for performance monitoring purposes. The performance monitoring should generate exception reports, which highlight the occurrence of any anomalies or trends that occur.

3.2.1. OBJECTIVES

The objectives of in-service dependability activity may vary between items and their different roles, but will generally include one or more of the following:

a. To quantify the achieved dependability.

b. To demonstrate compliance with specified dependability requirements.

c. To identify the factors inhibiting an item from achieving the specified levels of dependability.

d. To validate Life Cycle Environment Profile assumptions used in the predicted dependability studies.

e. To improve dependability. This could include incentives, penalties, or the establishment of additional dependability goals in a cost effective manner with the use of specialized warranty arrangements if applicable.

f. To assess the requirements and capabilities of technologies which are new to the military services and to provide information for the user and for future acquisitions.

g. To assess the effectiveness of maintenance procedures and built-in equipment, including the training of personnel engaged in such tasks, in the identification of failures.

h. To assess the remaining useful life of the item.

i. To use the observed dependability results to provide inputs to other functions such as obsolescence management, business planning and configuration management.

3.2.2. IN-SERVICE DEPENDABILITY CONCERNS

1. Understanding the materiel management issues related to in-service dependability performance is the vital first step in establishing a monitoring program. It provides the focus for the dependability data collection and analysis program by defining the key questions to be answered.

2. The identification of deficiencies in dependability performance: Dependability performance is of great concern to the users, and a proactive approach to identifying deficiencies will be invaluable in keeping them satisfied with their items. Examples of dependability performance deficiencies include item reliability degradation (higher failure rates, unexpected failure modes, premature wearout and so on), excessive maintenance costs (for parts, manpower, and other resources), high false alarm rates from automated test equipment, and low system availability.

3. Continuous flow of routine performance data: Support planning needs to be updated to reflect current realities. The support for a new item is initially designed using predictions developed in the design process that are often based on generic data. Information on actual field performance is needed so that adjustment can be made to the support system in time to avoid resource shortages or over-investment in inventory. This continues through the life of

the item. To meet these needs, information related to issues such as part consumption, support equipment and facility utilization, and the projected service life of the item is required.

4. Maintenance planning: Maintenance plans developed during the acquisition process must be validated for their applicability and effectiveness in the real world, and rationalized where necessary to reflect experience gained during the in-service period. This will involve such issues as monitoring rates of maintenance-induced failures for evidence of shortfalls in training or procedures, reviewing component life limits in light of growing experience, and evaluating the effectiveness of maintenance strategies, including opportunities to benefit from new predictive maintenance and diagnostic techniques.

5. Dependability performance data: This is required to support decisions on how best to resolve the problems that have been identified. The system evolution process encompasses modification/upgrade, service life extension and replacement choices. A good foundation of historical dependability data can be useful to ensure that proposed solutions address all the right problems, and to evaluate the likely impact of decisions on dependability performance and life cycle cost.

6. While the day-to-day issues of materiel management have a way of dominating the focus, it is also important to prepare for the future. Data on in-service dependability performance can play an important role in shaping the concept and acquisition of future acquisition programmes. It can provide performance targets for technical specifications and identify important “lessons learned”.

3.3. DATA COLLECTION FOR DEPENDABILITY

3.3.1. AIM AND OBJECTIVES

1. The aim of data collection is to generate information to make informed decisions which could lead to improvement of items and processes in any organization. Collected data with appropriate analysis close the learning loop back to design, manufacturing and service. Sub-targets can be risk minimization, cost optimization or the check for conformity with given requirements. Data should be collected for a purpose: to enable analysis, focused on increasing understanding of item operation and failure, and application of this knowledge to a goal or objective. Without a definition of the objective for the future data analysis and the application of its findings, collection of data is likely to be aimless and will omit important data, allow corruption of data, or may waste time and resources by including data that offer little benefit.

2. While planning data collection during the acquisition phase, several questions have to be considered to determine dependability requirements. It is important to remember that the underlying reason for performing data collection as a dependability task is to improve product quality, monitor performance, modify support, to determine if required reliability is achieved, identify deficiencies for root cause analysis leading to product improvement by modification, to improve performance and, in the longer term, to improve quality of service.

3. This aim leads to the need to understand all the costs associated with a particular project. These costs are known as the life cycle costs and include all costs involved in the design, manufacture, use and disposal of an item. Data collection plays a part in the identification of these costs since it allows management to make assessments of such things as value-for-money, cost effectiveness, and life-cycle cost.

3.3.2. DATA COLLECTION PROCESS

1. A comprehensive and accurate dependability data collection process is the key to managing in-service dependability performance. Data is the raw materials that allow informed decisions to be made regarding all of the dependability issues discussed above. Collecting the right data, and collecting it consistently over time, is the foundation of a good dependability performance monitoring program. Incomplete, inaccurate or sporadically-collected information generates more questions than answers, and is probably the biggest reason that many in-service dependability monitoring programs are abandoned in frustration.

2. Data collection to enable dependability analysis needs to record three basic types of data:

   a. *Usage data* describes how much the item has been used, and under what conditions the usage occurred. It provides a context for the failure and maintenance data.

   b. *Failure event data* captures the details of each failure - what happened, when and where it happened, why/how it happened and what impact it had.

   c. *Maintenance action data* describes all corrective (CM) and preventive (PM) maintenance actions performed - what was done, what resources (time and materiel) were consumed and how satisfactory were the results.

3. If the User or Supplier already has a proven data collection system, then there is no need for a dedicated system for collecting dependability data.

3.3.2.1. USAGE DATA

1. Forming a coherent picture of dependability performance is only possible when comprehensive data on usage is available to put events in context. For example, it is important to see whether any special factors (such as unusual operating conditions or a change in mission/role) may have had an effect on operation. All usage data should be recorded. Considering only the items that have failed can skew the results in an unreasonably pessimistic way.

2. Usage data is usually collected electronically through the maintenance transactions. From these maintenance transactions, reports can provide historical record of the usage and events as defined by the user. Some of the most important information to be collected includes:

   a. <u>Operating Time/Usage</u>: the accumulated operating time (or other usage measure) should be recorded at regular intervals (this is used to establish usage patterns over time and across the fleet). Any actions, which alter operating time records (for example, odometer replacement), should be captured.

   b. <u>Availability Related Information</u>: item status (up, standby or downtime, with reasons for downtime) should be recorded to allow the time spent in each category to be computed.

   c. <u>Events</u>: the occurrence of all events (for example, failures, maintenance actions, overhauls and inspections) should be recorded (with a cross-reference to the associated reports). Major changes to the operating role (for example, transfer from operations to training) or location (for example, deployment to the Arctic) should also be recorded, to provide historical information about the operation experienced over time.

d. Environmental data: Environmental data such as temperature, humidity and shocks should be recorded to provide historical information about the environments experienced over time.

e. Configuration: changes in the configuration status (for example, incorporation of permanent or temporary modifications/upgrades) should be recorded to identify the physical status of the item.

f. Unique Identification: If an item has a unique identification number, it should be recorded. This data can be used to establish the history of the items when analyzing its usage.

3.3.2.2. FAILURE EVENT DATA

1. Meaningful analysis of failure events demands as much qualitative and quantitative information as possible about each event, including the circumstances surrounding its occurrence, the effects that were observed and any cause that was eventually established. The information will be needed when grouping them for analysis, when looking for special factors that might have contributed to them, and when assessing the effectiveness of preventive maintenance strategies. It is important to record data on all events, including events where no fault was found, or where maintenance was performed quickly and without consuming parts. Such events often provide important clues about subsequent failures.

2. Failure data are often collected on a dedicated failure report, but failure and maintenance data may equally well be combined in a single report. Failure data are best captured by someone who observed or discovered the failure, but the cause of the failure should be verified by maintenance or other technical personnel. Some of the important information to be captured on each failure event includes:

a. Description: a brief description of the failure should be provided to summarize the event (this will often be the first piece of information examined by anyone looking for failure patterns, so it needs to be clear and concise), along with a cross-reference to any related failure events (such as a primary failure that caused this failure event, or secondary failures that were triggered by the failure event).

b. Identification: the name and identification/registration number of the major system (for example, vehicle, aircraft, ship, etc.) sustaining the failure must be recorded.

c. Time of Occurrence: the date and time of the failure must be recorded (indicating whether this represents the time that the failure occurred, or the time it was discovered), as well as the accumulated system operating time (including all clocks/meters related to usage of the failed item). This is necessary for ordering failures chronologically or by age at failure, and placing them in a historical context in terms of system usage.

d. Conditions Prevalent at the Time: the major operating and environmental conditions at the time of failure should be recorded, emphasizing anything that might have put significant/unusual stress on the failed item.

e. Detection Methods: the manner in which failure was detected should be captured for use in validating preventive maintenance strategies and refining diagnostic methods.

f. Effects of Occurrence: the effects of failure on the failed item and on system performance should be recorded to permit assessment of failure severity/criticality and to validate RCM analysis.

g. Root Cause: the cause of the failure (including attribution to hardware, software, operator error, maintainer error, accident, etc.) should be recorded, including the initial impressions or suspicions of Users and first line maintenance personnel, as well as any confirmation provided by failure investigations or further maintenance ("cannot duplicate", "no fault found" or "re-test ok" findings should be included). This is vital when grouping failures for analysis.

h. Recovery: the action taken to remedy the failure should be captured, including any initial steps taken by Users to restore mission capability, as well as maintenance performed to return the item to a serviceable state.

i. Additional Data: some types of failures, such as software failures, may require the capture of additional information, perhaps requiring downloading of this information to assist in troubleshooting and problem isolation.

3.3.2.3. MAINTENANCE ACTION DATA

Maintenance action data describes all corrective (CM) and preventive (PM) maintenance actions performed. Some of the important information to be captured on each maintenance action includes:

a. Task Identification: the maintenance task must be described briefly, along with the reason for performing it (for example, a reference to a failure report for a corrective maintenance action, or to a preventive maintenance schedule for preventive maintenance).

b. Task Time: the duration of the maintenance should be recorded, along with the calendar date and time that the action started and finished. The source and duration of any delays encountered before or during the work should also be identified.

c. Labor Consumed: the maintenance manpower required to perform the task should be identified by maintainer, including trade and skill level as well as labors expended.

d. Parts Consumed: the identity and quantity of parts consumed by the task should be listed, and the disposition of repairable items should be recorded. If a spare or repair part has a unique identification, the identity of the parts removed and replaced should be recorded.

e. Problems: any problems with maintenance resources (for example, incorrect diagnostic or maintenance procedures, inadequate tools or test equipment, defective spare or repair parts, or insufficient training) should be recorded

3.3.3. DATA COLLECTION ISSUES

1. There are several general principles that can contribute greatly to the success of a dependability data collection system, all of them focusing on data quality. Without good data quality, dependability performance analyses will produce misleading results (if they can provide anything at all), which can lead to unjustified complacency or unwarranted concern. Either way, the wrong course of action will be suggested.

2. Simple transactions, quick to complete, are an important way to ensure the timely collection of data. Each question should be clear, even to a new user. Pre-defined check boxes and codes could be used to minimize data entry wherever is possible. Over-collecting data is a burden to the user, it leads to poor data quality as they become frustrated with questions that are not applicable to their situation, or require more information than they have. Data quality is more important than data quantity.

3. Every effort should be made to avoid the duplication of data entry. For example, if a maintenance report is also used for work authorization and for ordering parts, it will streamline the workload rather than add to it.

4. Data collected electronically needs to consider bandwidth requirements, security issues, storage issues and so on.

5. There will always be some degree of variation in the quality of data collection -- between units, between users, and for the same user at different times (depending on workload, attitude and training). The data collection process should be routinely audited to assess data quality and point out areas that need improvement or reinforcement, so that problems can be addressed before the system is irretrievably corrupted with unreliable data.

3.4. DATA ANALYSIS FOR DEPENDABILITY

1. Whether data is used for routine dependability performance monitoring or for more focused investigations, it needs to be reviewed for completeness and classified according to a logical and structured process. A method for executing this process is described in ADMP-03. Implementing this process is how the “collected data” becomes “information” that can be used to inform the decision making process.

2. There are many types of information that can be extracted from data, and a corresponding selection of analysis and presentation methods. Data analysis can help to identify the major contributors to a problem (for example, what is causing most of these failures?). It can also reveal which factors have a significant impact on a problem (for example, will controlling or compensating for this factor help to fix the problem?). Data analysis over time helps to detect deviations or anomalies that should be investigated (for example, has something just happened that needs attention/explanation?). It also identifies trends over time (for example, is this process undergoing a permanent change from its usual state?). Relatively simple analysis methods include Pareto analysis, stratification, scatter diagrams, and control charting. Information on additional advanced techniques (such as Analysis of Variance) can be found in texts on statistics and quality assurance. Dependability data can be used with techniques such as Root Cause Analysis (RCA), Reliability Centered Maintenance Analysis (RCM), and Condition Based Maintenance (CBM). A variety of statistical analysis software packages are available to automate these analyses. The International Electrotechnical Commission (IEC) offers several publications (through the Technical Committee (TC-56) publications standards on Dependability Management) that directly explain how to use these techniques.

3. A wide range of dependability measures are available for application, but selections will vary from project to project, depending on the type and function of the item, the needs of the users and the available data sources. At the top level, these metrics can be grouped under the typical measures under dependability management such as reliability, maintainability, availability, testability, maintenance, and safety, and more details can be found in ADMP-01.

3.5. MAKING DECISIONS

3.5.1. GENERAL

1. Once a dependability problem has been identified in analysis, the next step is determining if anything can be done to improve the situation. Decisions will seek to satisfy operational effectiveness requirements and maximize cost effectiveness over the remaining service life.

2. Figure 2 below shows a process for identifying which dependability improvements are worth including in a program.

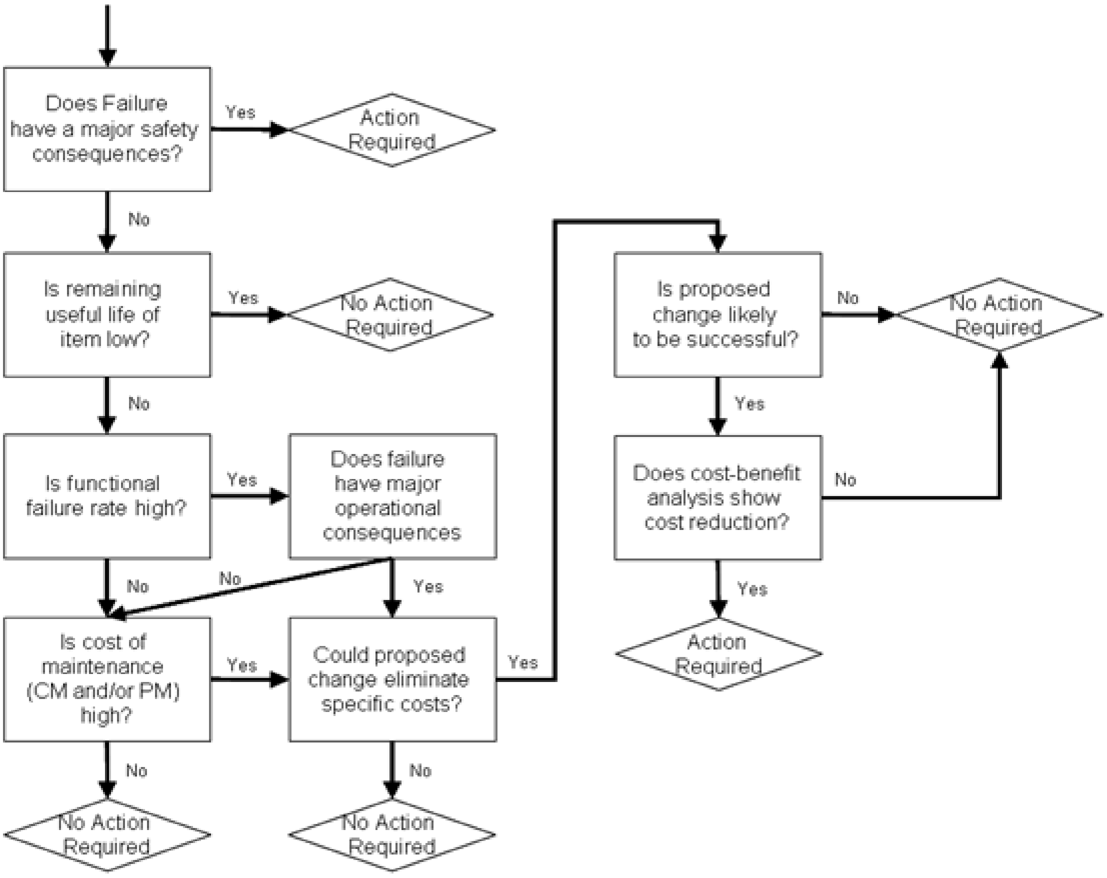

FIGURE 2: Dependability Improvement Decision Process

3. Any change provides a chance to improve performance, and also a risk of inadvertently damaging it. Careful project management fosters the improvements and minimizes the penalties. From a dependability perspective, all of the considerations encountered during the item design come into play again. Every change must be evaluated for its impact on dependability performance. However, there is a benefit to working on a mature, fielded system. Performance monitoring records and other dependability performance indicators can provide a list of the biggest shortcomings faced by users under actual field conditions.

3.5.2. CORRECTIVE MAINTENANCE ACTION OPTIONS

1. Corrective maintenance action options, such as better preventive maintenance, modification to design and process, overhaul, life extension or replacement will depend on what is technologically feasible or cost effective;

2. An improvement in the maintenance program may reduce exposure to the consequences of the item failure, or decrease maintenance costs without jeopardizing dependability. A modification or upgrade to the item may improve dependability performance by fixing major problems. A life extension program may renew the item, postponing the problems of wear out until some point in the future. Replacement of the item might eliminate dependability problems associated with old technology and poor design, allowing a fresh start to be made. However, it is not always possible to fix the problem and the user must simply live with it.

3.5.3. LIVING WITH DEPENDABILITY PROBLEMS

1. In some cases, a dependability performance problem may be identified but no viable options exist for fixing it. This may happen when a technical solution cannot be identified, or the necessary fix is not cost-effective. Or perhaps there is no money available to perform a fix, no matter how cost-effective it is. It may also happen towards the end of the item’s life, when a decision on modification or replacement has already been taken.

2. The person responsible can still take useful actions to ease the pain of living with the problem. The most important step is to alert people to the existence of the problem, so that resources can be adjusted to meet any increased demand in time that may be required to avoid a negative impact on operations. Increased quantities of spare and repair parts may be required. Repair and Overhaul (R&O) facility may have to prepare for increased throughput. Turn-around time for spares procurement and R&O may have to be shortened. More maintenance resources (personnel, tools, test equipment, facilities) may be needed to cope with increased workloads. Educating users and maintainers about the problem may allow them to identify work-arounds (for example, conscientiously avoiding “rough treatment” or heavy use that might trigger the problem). Increased efforts to balance usage rates across the fleet may postpone the onset of age-related problems.

3. It may also be possible to minimize exposure to a dependability problem by formally restricting the operational use of the item. For example, if operating in particularly cold weather is known to cause the problem, it may be possible to avoid using the item in such situations unless it is absolutely necessary.

4. Finally, gathering data and documenting the problem is a proactive step to prepare for a day when a fix may be possible. Having the information available will make it easier to influence the specifications for a future modification or replacement program, to make sure that the problem does not recur.

3.5.4. MAINTENANCE IMPROVEMENT

1. The maintenance program for any item should be expected to evolve during its life as more experience is gained with its operation, reliability and failure modes. In-service events may force a change in the maintenance program when it becomes evident that the causes and/or consequences of some failure mode have been misunderstood. For example, a

maintenance review should be conducted immediately after the first occurrence of a safety failure, to see whether it was just “bad luck” (random variation), or whether the maintenance strategy failed to reduce the probability of failure to an acceptable level. Similarly, the persistent occurrence of any failure modes that were supposed to be covered by a preventive maintenance task should cause a review of the task’s effectiveness (Does condition monitoring or inspection provide adequate warning of failure? Is the scheduled overhaul or replacement interval too long?). The discovery that a functional failure is actually hidden from the users should also cause a review of the Reliability Centered Maintenance Analysis (RCM) for that failure mode.

2. Analyzing the effectiveness of preventive maintenance tasks may reveal an opportunity for improvement. If a scheduled inspection is rarely finding anything wrong, it may be time to increase the inspection interval. If teardown of items removed for scheduled rework shows significant life remaining, an increase in the life of the item may be justified. If failure reports indicate a high incidence of maintenance-induced failures on items that are being preventively-maintained, it may be that preventive maintenance is doing more harm than good. A different strategy (or perhaps better training of maintenance personnel) may be called for.

3. Analysis of preventive maintenance tasks may reveal that costs could be reduced by a change in policy, based on actual experience with failure rates, maintenance costs and failure costs.

4. Technological change can cause a review of preventive maintenance strategies. A new inspection method may be capable of detecting potential failures significantly sooner, permitting the inspection frequency to be decreased. Condition monitoring may become more cost-effective, allowing predictive maintenance to replace time-based inspection strategies. Newer versions of interchangeable replacement parts may provide longer life. Modifications or upgrades may also provide an avenue to improve preventive maintenance methods.

3.5.5. MODIFICATIONS AND UPGRADES

1. Many items go through at least one significant modification or upgrade during their service life. There are many reasons to contemplate such changes (for example, to boost performance, or to maintain compatibility with newer item), and not all of them relate to dependability performance. Whether or not dependability drives the initiation of the work, it should always be a major factor in the planning; however, at times external factors can mean that dependability is not the primary driver (for example, national/international legislations) and can decrease.

2. The important idea about any modification is that it represents a “second chance”, an opportunity to fix problems with the benefit of hindsight, while doing the job right on new areas of design. There is a danger, however, in making improvements to long-standing deficiencies simply because it has become possible. Instead, a disciplined approach for justifying dependability improvements on a cost-benefit basis is appropriate. Any redesign effort will involve some degree of expense, and it is important to identify a payoff that will offset the costs.

3.5.6. LIFE EXTENSION

1. Life extension involves overhauling an item to renew its service life. It may also include modifications or upgrades to cope with changing operational requirements, or to postpone

obsolescence. A life extension program may be an attractive alternative to replacement for reasons of cost, schedule and/or performance.

2. If service life comes to an end more quickly than expected, life extension may be the only choice available in the short term, until a replacement item can be developed or acquired. Even if replacement options are available, it may be useful to allow some time for assessing the merits and risks of each one, or to wait for a promising new alternative to prove itself.

3. Life extension may be the most cost-effective way to renew an item. If life is being limited by a small portion of an item’s components, then an overhaul may restore service life relatively cheaply. Similarly, life extension may be the best option to fill a role that will be phased out over the medium term (rather than acquire a new item that will only be used for a time).

4. If an item is still quite capable of meeting all relevant performance requirements, then a life extension program may be the best way to retain that capability. The considerable overhead and disruption caused by acquiring and fielding a new item is difficult to justify if the old one can be renewed to do the job.

3.5.7. REPLACEMENT

Every item reaches the end of its service life at some point, and it becomes undesirable (perhaps even impossible) to keep the system operating. Service life may be ending when the item can no longer deliver the required level of performance, in terms of either cost or benefit. Its operating and maintenance costs may be rising to unacceptable levels. The quality and/or quantity of its output may have dropped to a point where it can no longer meet the operational requirement that it is supposed to fulfil.

3.5.7.1. LIFE-LIMITING FACTORS

1. For most items, several factors are competing to bring service life to a close, either sharply or gradually. From a dependability perspective, wearout is the life-limiting factor of most concern.

2. Wearout is an inevitable process of degradation, due to mechanical and electro-chemical processes, that renders an item increasingly incapable of performing its function. Maintenance can counteract the initial effects of wearout to some degree, but the process is relentless. The item will finally reach the end of its *durable life*, at which point no reasonable amount of maintenance can restore it to a serviceable state. Examples of such conditions include fatigue cracking of major structural components, or widespread deterioration of wiring harnesses that are “built into” a system such as a ship or aircraft.

3. Overstress occurs when the user demands more performance from an item than it was designed to deliver. Overstress is not inevitable, but it is an increasingly likely occurrence for older items. The user’s needs often change as time goes on resulting in a demand for the item to operate at higher speeds or handle heavier loads. Understanding the impact of the overstress of the system is paramount as it can significantly reduce the life of the system.

4. Defects can also bring an item to the end of its life. When major design or manufacturing flaws are discovered after an item has been fielded, it may be fundamentally unable to perform the function that it was designed for. No amount of maintenance will help to restore a capability that never existed, and the only available option may be to start again almost from scratch.

For example, if the steel used to build an item was of insufficient strength, the item may be completely unable to handle its planned operating loads. A faulty thermal design might make an item's electronic circuits prone to fatal overheating under some operating conditions.

5. Obsolescence ends an item's service life when it can no longer function in the current technological and support environment. If an item cannot interface or communicate with newer systems that it needs to work with, then it has reached a point of technological obsolescence. For example, a computer that cannot connect to the new network or run the latest software may no longer be of use, depending on the user's needs. When an item can no longer be supported because spare and repair parts or consumables are unobtainable, or because the necessary maintenance skills are no longer in ready supply, then its service life is over just as effectively. Obsolescence is as much of a problem for software as for hardware.

6. It is important to understand in advance which factors will effectively limit the life of an item, and to determine when that limit will be reached. This is necessary so that a strategy for item renewal or replacement can be put in place before the end of service life arrives. It is too late to begin procuring a complex new item on the day that the old item crashes irretrievably.

3.5.7.2. DEVELOPING AN END-OF-LIFE STRATEGY

Planning for the end of service life must be proactive. Figure 3 below illustrates the general process of identifying how and when service life will end, then evaluating replacement or renewal all options to determine the best choice. Whatever decision is reached, the remaining life of the item can now be managed appropriately. For example, expensive repairs or modifications can be avoided if they will not provide an adequate pay-off before the end of service life.

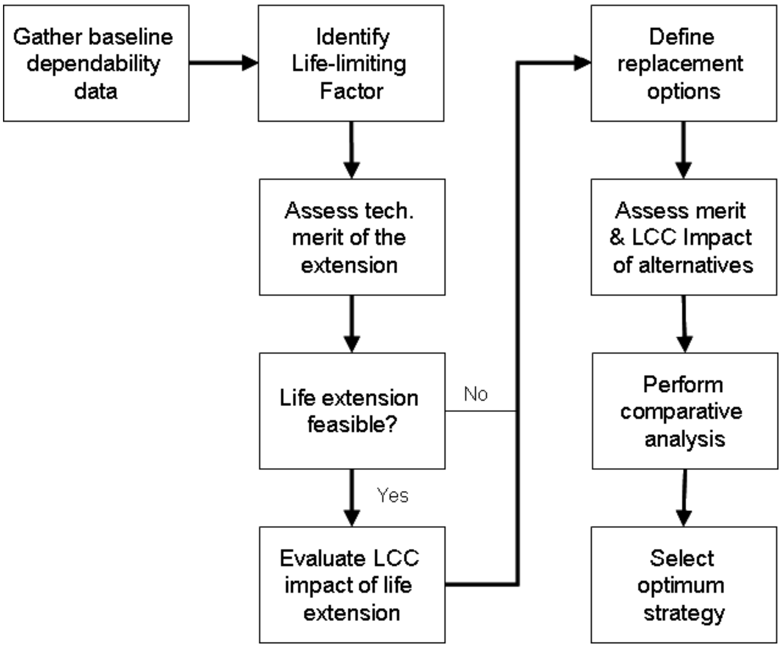

FIGURE 3: Developing an End-of-Life Strategy

3.5.7.3. REPLACEMENT DECISION CRITERIA

1. Notwithstanding the possibility of life extension, most items will eventually have to be replaced. The decision on exactly when to replace an item is often driven by dependability considerations, such as increasing maintenance costs, falling levels of item effectiveness and growing risk of unacceptable failure consequences. The common factor in all of these criteria is that they are continuous measures. For example, there is no definitive point at which an item is "too expensive to maintain", only an arbitrary threshold established to guide decision-making, or a point at which alternatives are perceived to be more cost-effective. The role of dependability data in replacement decisions is to define current and expected levels of reliability, maintainability and availability for an existing item and its potential replacements, so that an informed choice can be made.

2. With dependability performance predictions available, better informed replacement decisions can be made. There are three main types of criteria generally used to make such decisions. Optimization criteria seek the solution that will minimize costs or maximize benefits. Acceptability criteria define performance thresholds that must not be crossed if operational requirements are to be met. Obsolescence criteria ensure that new performance requirements and technological change are taken into account. It is appropriate to blend these criteria by seeking the optimal replacement policy which meets all relevant acceptability and obsolescence criteria.

3. Acceptability criteria are often used as the trigger for a replacement decision, defining the worst level of performance that is tolerable from an item. Replacement may be required when an item cannot deliver a minimum level or quality of performance, when it is down too often, when it costs too much to operate and maintain, or when a low level of safety or dependability presents an unacceptable risk.

4. Dependability information can help to forecast when an item is likely to breach an acceptability threshold (such as a maximum downtime or minimum dependability requirement). An accurate forecast will allow time to plan for replacement action, rather than waiting until performance has actually reached unacceptable levels and operations (or budgets, or safety) begin to suffer.

5. In addition to meeting acceptability criteria, the best replacement decision will optimize cost (or cost per unit of benefit) over an appropriate planning horizon.

CHAPTER 4 FAILURE ANALYSIS

4.1. GENERAL

Failures are obviously undesirable events, but they are also useful. They provide important information about an item's weaknesses, so every failure becomes an opportunity for improvement. Taking advantage of these opportunities requires a rigorous approach to the failure analysis process, so that none of the potential insights provided by a failure are wasted.

4.2. FAILURE REPORTING ANALYSIS & CORRECTIVE ACTION SYSTEM (FRACAS)

1. A closed-loop Failure Reporting and Corrective Action System (FRACAS) promotes a thorough approach to failure analysis. It ensures that the valuable information provided by failures is captured for input into any subsequent failure investigations. Failure investigation is a continuous systematic process of physical failure analysis, failure data review and root cause analysis to understand why a failure occurred. The investigation results provide the foundation for taking appropriate corrective action. (See Figure 4).

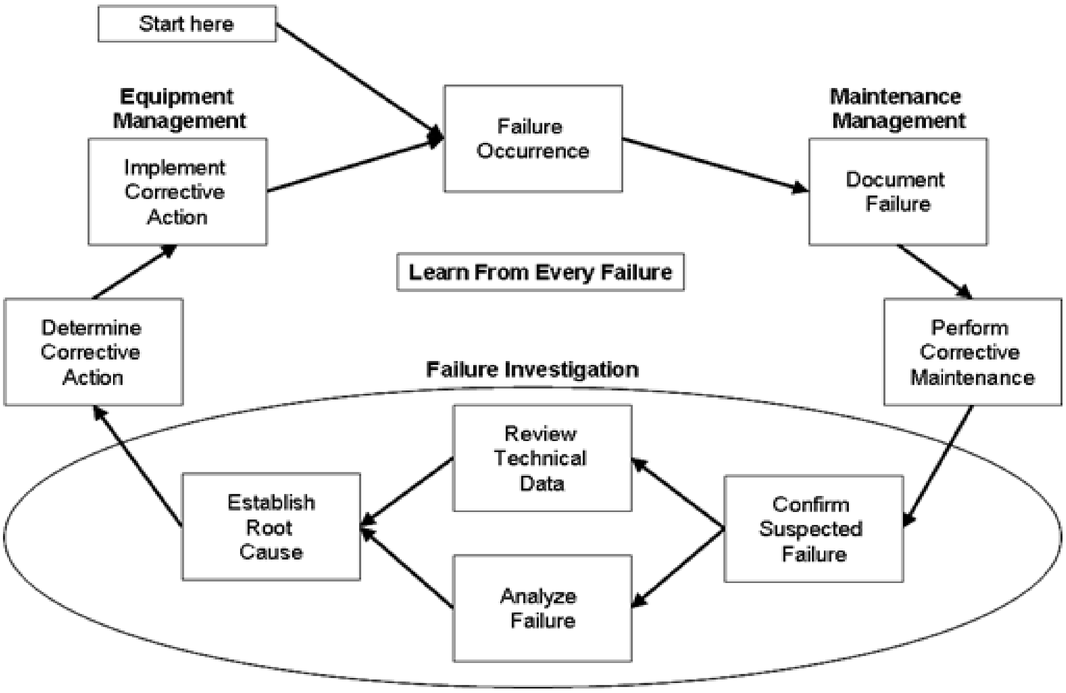

FIGURE 4: Failure Reporting, Analysis & Corrective Action System (FRACAS)

2. A FRACAS should normally be set up during the design and development phase of a program, to support the "test, analyse and fix" process. It continues to operate during production, to deal with failures identified in the factory and during installation. By the end of this period, the FRACAS may contain a large volume of failure data, failure analysis reports and information about failure patterns.

3. Although its focus is rather different, FRACAS should continue in-service. Changes to product designs and manufacturing processes are less likely to be possible, so corrective actions will take other forms. The existing maintenance management information system can be used for the failure reporting function.

4.3. FAILURE INVESTIGATION

1. The failure investigation process begins with the identification of a problem, in the form of a failure (or failures). Its objective is to determine the root cause of the problem, so that appropriate corrective actions can be identified. It is important not to jump to conclusions about the root cause. Labelling and fixing the wrong thing will only create a false sense of confidence.

2. The top level of the failure investigation process is straightforward. First, the failed item is examined to confirm that it has truly failed, and that there is a problem worth investigating (this avoids wasting time on failure analysis when the problem lies with a faulty maintenance diagnosis). Next a physical failure analysis is performed to establish exactly how the item failed. At the same time, a review of technical data is conducted to provide further information about the failure and its possible causes. Finally, the results of the physical failure analysis and the data review are used as inputs to a root cause analysis, which determines why the failure occurred and how far its impact might extend. This knowledge forms the basis for proposing corrective actions, and ends the failure investigation process.

4.3.1. FAILURE ANALYSIS

The failure analysis examines the failed item to establish the mode, mechanism and proximate (immediate) cause of its failure. The analysis may use any of a number of techniques, depending on the technology and materials used in the item, the nature of the failure, and the resources available.

4.3.2. TECHNICAL DATA REVIEW

1. The data search, which proceeds concurrently with the failure analysis, has two purposes. First, it looks for information that may help to direct the failure analysis. This includes technical data which define the intended performance of the failed item, and describe the parts, materials and manufacturing processes used in its construction. It also includes failure reports, operational alerts or other technical literature relating to similar failures, which may indicate that particular inspections and tests would be useful.

2. Second, the data search looks for information that could help to identify the root cause of the failure. This involves an examination of failure reports to identify any patterns of similar failures. It also includes a review of historical data related to the failed item (such as manufacturing records, quality records, acceptance test reports, in-service operating logs and maintenance reports). It may also include a review of technical manuals that describe the intended operation and maintenance procedures for the failed item.

4.4. ROOT CAUSE ANALYSIS

1. Once the proximate cause of the item's failure has been established, further investigation may be needed to determine the root cause, and to determine whether any other items might be vulnerable to the same root cause. Root causes can be found in many places and take many forms. Typical sources of root causes which should be considered in any analysis are shown below:

   a. Design

   b. Components & Material

   c. Manufacturing

   d. Overstress

   e. Maintenance

   f. Wearout

2. In some cases, the root cause will be quite apparent and the corrective action obvious. In other cases, the root cause will be more difficult to pinpoint. Additional analyses may be required, and more failures may have to occur before enough of a pattern emerges to justify a conclusion.

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