# Applied R&M Manual for Defence Systems

# (GR-77 Issue 2012)

## Foreword

GR-77 was the *"traditional bible"* of the AR&M community. As part of their remit to provide advice on *"AR&M"* the DGSS team extracted those relevant items and produced the original version of this manual. Since the production of the manual numerous evolutions have occurred to both the DPA and DLO reliability cells. Under Defence Equipment & Support there is now one reliability team supporting new procurements and in service equipment. Previous reductions in resources have constrained the Team's ability to update the manual as often as they may wish. However, new papers of relevance have been added where these have become available as a by product of other activities. Additionally as an interim measure, extracts from relevant Defence Standards have been included; these are identified by the Version 0.9 number.

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May 2012

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## Part A General

There are a number of high level subjects to be addressed in any manual. These form an introduction and set the scene. Here they look at R&M in general, how R&M relates to other engineering disciplines and what it consists of at a high level.

**Chapter 1 Introduction to the Manual**

General comment on the background, purpose, scope, etc.

**Chapter 2 Acronyms and Abbreviations used in R&M work**

A list of acronyms and abbreviations used elsewhere in the manual.

**Chapter 3 Glossary of R&M Related Terms**

A list of terms used elsewhere in the manual. Some developing terms are worthy of comment here.

**Chapter 4 Examination of the Overall R&M Activity**

A structured breakdown of the overall R&M Activity. This addresses the basic areas of R&M activity and their relationship with non-R&M activities and other R&M activities. It takes the form of a structured analysis and decomposition of the process.

**Chapter 5 R&M Processes**

Reliability and Maintainability Process provide a comprehensive step by step guide to managing the R&M aspects of specifying, acquiring, fielding and maintaining equipment throughout the CADMID cycle. The maps do not specify how individual equipment should be managed but enable informed decisions and programmes to be developed to optimise the acquisition and through life management process.

**Chapter 6 R&M and Project Risk**

R&M is often (incorrectly) seen as a peripheral activity in the development process for a new system. This chapter addresses the risks to a project of not considering R&M requirements at the appropriate time and with the necessary level of commitment. A positive approach is given, aiming to give project managers an understanding of the level of risk being taken and how that might be reduced.

**Chapter 7 R&M as a System Engineering Discipline**

R&M is an essential part of system design. This chapter explains the integrated nature of R&M requirements and their relationship with functional and other requirements.

**Chapter 8 Computer Aided Engineering Tools for R&M**

Computer Aided Engineering is becoming more and more prevalent. This is also true in the R&M field. Many tools are available and much R&M work is done using spreadsheets and databases. This chapter aims to list the DGSS supported tools and make general comments (benefits and pitfalls) about the use of these and other tools.

**Chapter 9 Modelling**

A model can be defined as a 'simplified representation of a complex system or process'. Modelling is used to provide evidence of the behaviour of a system or process before the system is built, the process initiated or costly decisions are undertaken. This chapter describes the fundamental stages of modelling activities, as applied in the R&M arena, and considers some of the problems encountered.

**Chapter 10 R&M Guidance for the Acquisition of Off the Shelf (OTS) Equipment and Systems Based on OTS Components**

This document provides guidance on the R&M activities with respect to the use of OTS technology in MoD procurement. These guidelines provide an approach to OTS procurement in terms of R&M which satisfies the requirements of Defence Standard 00-40 Part 1, but embraces the objectives of OTS procurement, chiefly lower procurement and support costs.

## Part B R&M Related Activities

The structured decomposition (Part A Chapter 4) identifies a number of activities that are undertaken under the banner of R&M. Each activity has a purpose, in terms of producing a given type of information, and is performed through the use of one or more techniques (see Part C).

**Chapter 1 Potential Scenario Analysis**

Potential scenarios are considered in the early stages of designing a new system or of modifying an existing system for a new task. The effect of R&M performance parameters on functional performance, logistical support requirements and safety can be a key factor in determining the effectiveness of a proposed solution.

**Chapter 2 R&M Performance Specification**

The achievement of R&M in service stems from either luck or a clear, appropriate and realistic specification of the requirements together with a contract that enforces adherence. Various forms of specification exist and can be applied to differing parts of the specified system. There are also a number

of pitfalls to be avoided if the specification is not to become the subject of protracted discussion and eventually concessed.

**Chapter 3 Design for R&M Performance**

R&M is built into a system at the design stage. No amount of analysis or testing can improve a design without a costly revisit to the design stage. The use of good design practice for high reliability and good field maintainability (in software and hardware) is an essential component of reducing project risk and achieving good products.

**Chapter 4 Practical Review of Design for R&M**

The functionality of a system is well tested during the design process. The continuity of this functionality over time and the ability to return failed equipment to a functional state is equally relevant to achieving performance in the field. Various methods of testing are available and can provide useful feedback on the performance.

**Chapter 5 Theoretical Review of Design for R&M**

Practical testing can only sample the failure modes of complex modern equipment. Theoretical review and analysis complements practical testing and identifies where the defence against rarer, but important, situations is less than necessary or reasonably practicable.

**Chapter 6 Theoretical Estimation of R&M Performance**

Predictions are perhaps the best known and most misused tools of R&M engineering. They do have a valuable role in the project life cycle provided they are used appropriately and with knowledge of their shortcomings.

**Chapter 7 Failure Consequence Analysis**

The connection of failures and their effects, or conversely high level events and their causes, provides important insights into the control of undesirable events at the system level or beyond. A good model of the system failure modes facilitates the identification of the area of a system to be addressed in order to improve system R&M.

**Chapter 8 Practical Demonstration of R&M**

R&M Demonstrations are practical tests of the achievement of specified levels of R&M performance. They can be used to verify the achievement of specified requirements and to provide evidence to support reliability and safety cases.

**Chapter 9 Production Engineering for R&M**

The use of optimal practices in production (Part B Chapter 10) requires engineering to determine the areas where resources can be most effectively applied.

**Chapter 10 R&M Evidence Collation**

Evidence of the level of R&M performance provided is required for the initial acceptance of a system into service or even its continued use. Such evidence may also be required to support the safety case for the system or an assessment of the system's fitness for a given use.

**Chapter 11 R&M in Production and Maintenance**

The use of less than optimal practices in the assembly process has been identified as a major contributor to poor R&M performance in the field. It is therefore an important area to address if a product is to achieve its intrinsic reliability.

**Chapter 12 Cautions and Precautions in the Use of In-Service R&M Data**

The process of gathering data from in-service equipment is very beneficial to the performance of both current and future equipment. However such a process is fruitless unless all the relevant data is collected, stored and analysed.

**Chapter 13 Project Management and R&M**

R&M should be addressed by project management. R&M projects should be project managed. There are however some areas that require special consideration given the long term focus of R&M activities. These include: the use, and time taken by, statistical tests; the more abstract / statistical nature of the quantities involved; and the differences between passing R&M aspects and functional / environmental aspects on to sub-contractors.

**Chapter 14 R&M Data Management**

R&M is a data intensive subject. Predictions specifically use past data. Often the quality of the information produced by an R&M activity is directly related to the quality of information available. The management of data, particularly historic data from other system, is key to engineering success in the future.

**Chapter 15 Software R&M Analysis**

This chapter discusses the techniques appropriate to the analysis, assessment and progressive assurance of the R&M characteristics of software. Techniques to be applied during each phase of the system's Life Cycle that assist the development and maintenance of software with adequate integrity and their application are discussed which are often interactive and iterative.

**Chapter 16 Representing the Initial R&M Case Using Goal Structuring Notation**

This chapter provides a discussion of how the Initial R&M Case may be represented using Goal Structuring Notation (GSN). The approach may be equally used to present any situation where one wishes to make a claim and where the support for that claim will be based upon evidence and argument.

## Part C R&M Related Techniques

The activities above are achieved by applying R&M techniques. There are many techniques that have been developed over the years. This section aims to present a fairly comprehensive set of techniques but can not guarantee to cover all techniques.

### Chapter 1 Operational Needs Analysis

In terms of R&M, Operational Needs Analysis addresses the effect of various level of R&M on the delivery of functionality. The levels of R&M considered will be influenced by the practicality and cost of their achievement. It therefore contributes to the determination the appropriate R&M requirements to be specified.

### Chapter 2 Environmental Conditions Analysis

The environmental conditions are not really within the remit of the R&M function. However they do affect the R&M performance and this aspect is usefully included in this manual.

### Chapter 3 Modification Impact Analysis

Any modification carried out on a system will impact upon other system performance parameters in addition to those that are key to the purpose of the modification. The R&M performance is very likely to be altered by every modification. Impact analysis aims to determine the extent of this alteration at a stage when this can be considered in the decision on proceeding with the modification.

### Chapter 4 Trade-Off Studies

During the specification and design stages, a number of solutions are likely to be under consideration. A number of factors should be considered in deciding between solutions. One of these is R&M. This chapter concentrates on the R&M aspects of trade-off studies.

### Chapter 5 R&M Allocation and Apportionment

Once R&M requirements have been set against high level functions or equipment assemblies it is necessary, as part of the design process, to identify the allowable contributions from the lower level items of equipment. This is particularly so when these items are being produced under separate or sub-contracts.

### Chapter 6 High Integrity Specification (of all types of system and equipment)

The design of equipment (particularly software) with a reliability requirement beyond that which is practically testable during the pre-delivery and early service stages of a systems life has been addressed in recent years. Although the solutions currently available can not be seen as perfect, best practice should be followed. This applies to both the specification area, where appropriate wording is required, and the design, where appropriate techniques must be used in order to make the necessary claims in the acceptance phase.

**Chapter 7 Derating**

Part derating is a long established reliability technique although perhaps now with different justification to that applied in the past. Recent research has shown that the relation of reliability and temperature is not as defined by the Arhenius equation. However derating is still valuable in ensuring that elements of the system are operated within their specification even when subjected to external events beyond the limits defined in the specification.

**Chapter 8 Lifed Item**

The designation of certain items as 'lifed' remains a valuable tool in controlling mechanisms of failure. Its use is not popular from a logistical viewpoint, particularly when built in test can detect failure of the lifed item. This section explains their operation and discusses their use.

**Chapter 9 Critical Item**

Critical items are another valuable tool that is often misused. This section explains their operation and discusses their use.

**Chapter 10 High Integrity Design**

The best point to introduce high reliability is in the specification and design phases (a right first time approach). This is particularly so in the software area where Def-Stan 00-55 requires specific activities to be performed during design. This chapter addresses the usage of detailed techniques and references appropriate literature.

**Chapter 11 Redundancy Optimisation**

The use of redundancy needs to be well thought out. This chapter addresses the need, benefits and pitfalls.

**Chapter 12 R&M Design Criteria**

On a large project it is useful to define criteria for the design process to follow. This chapter addresses the setting, monitoring and dealing with deviations from such criteria.

**Chapter 13 Test, Analyse and Fix**

Test, analyse and fix is a practical approach to identifying and resolving the weak areas of a design. This chapter discusses the application of the technique.

**Chapter 14 Step Stress Testing**

This chapter discusses the application of the step stress technique and comments on its advantages, applicability to situations and the constraints.

**Chapter 15 Reliability Growth Testing**

This chapter addresses the technique of reliability growth testing, its application, its advantages and problems that may be encounted.

**Chapter 16 Highly Accelerated Stress Testing**

The benefits and short comings of highly accelerated stress testing, together with the process are addressed in this chapter.

**Chapter 17 Ease of Maintenance Assessment**

Ease of Maintenance Assessment (EMA) is the means whereby the Project Team confirms whether equipment can be maintained in-service and meets the maintainability and ease of maintenance criteria within the maintenance strategy. This chapter provide guidance for the production and publication of EMA Reports.

**Chapter 18 Data Reporting, Analysis and Corrective Action System**

This chapter addresses the DRACAS process, the collection flow and storage of relevant data, its analysis and closing the loop to achieve improvements.

**Chapter 19 Sneak Circuit Analysis**

Sneak circuits are circuits (normally electronic although the principle applies to electrical, pneumatic and hydraulic) outside the main functional path that might affect the function. An example includes the passage of a signal through monitor connections, power supply lines and the capacitative coupling of an amplifier's input and output causing oscillation. This chapter discusses the aims, application and benefits of such analysis.

**Chapter 20 Tolerance Analysis**

Any design is implemented using components with actual values slightly different from the ideal. Statistical consideration of the effect of these inaccuracies on the accuracy of the output is of benefit to the design review process and can lead to changes that reduce production cost and increase reliability. The chapter addresses the process, aims and benefits.

**Chapter 21 Built-In-Test Effectiveness Analysis**

The effectiveness of built in test is important to availability in that the built in test initiates corrective maintenance. This chapter addresses the appropriate examination of the system and the application and extension of the FMECA technique to elicit the relevant results.

**Chapter 22 Testability Analysis**

Poor testability increases the probability of equipment going into service with latent faults. This can reduce the exhibited reliability from that exhibited during design testing. This chapter discusses the ways of performing such analysis and the benefits thereof.

**Chapter 23 R&M Checklists**

R&M checklists provide a rapid check of important aspects of a design. This chapter addresses their content, tailoring them to a particular review and the benefits obtainable.

**Chapter 24 Physics of Failure**

The physics of failure technique aims at identifying the optimum location in a design to apply resource in order to improve reliability. This chapter discusses the process, the benefits and the use of the results.

**Chapter 25 Worst Case Stress Analysis**

All prediction work becomes invalid if any part of the system (however small and seemingly insignificant) is used outside its operating envelope. Worst Case Stress Analysis looks for such 'weak links' in the system. The chapter addresses the application and benefits of the technique.

**Chapter 26 Goal Structuring Notation**

Goal Structuring Notation (GSN) is a graphical notation for presenting the structure of engineering arguments. The approach may be used to present any situation where one wishes to make a claim and where the support for that claim will be based upon evidence and argument. This would include situations such as R&M, safety, support or legal based cases.

**Chapter 27 Fault Tolerance Analysis**

This chapter discusses the application, benefits and use of the results of Fault Tolerance Analysis.

**Chapter 28 Dependent Failure Analysis**

This chapter discusses the application, benefits and use of the results of Dependent Failure Analysis.

**Chapter 29 Fault / Success Tree Analysis**

This chapter discusses the application of Fault Tree Analysis and the modifications to perform Success Tree Analysis.

**Chapter 30 Reliability Block Diagrams**

This chapter discusses the application of the RBD technique.

**Chapter 31 Human Impact on R&M**

Human impact on R&M is a separate technique to Human Reliability Assessment but a major support to it. The chapter addresses the application and use of the technique.

**Chapter 32 Human Reliability Assessment**

Human reliability is an area of growing concern. The chapter looks at the technique for assessing human reliability and using the results to achieve positive improvement.

**Chapter 33 Failure Mode, Effects (and Criticality) Analysis (FMEA/FMECA)**

FMECA is a well known technique but needs explaining with emphasis on the purpose, tailoring of worksheets and use of the results.

**Chapter 34 Event Tree Analysis**

ETA is a well established technique. The chapter explains its use and how to link it to FTA for an overall cause-consequence view.

**Chapter 35 Availability Prediction**

Availability is predicted by combining reliability and maintainability. This chapter concentrates on ensuring that all the correct elements are combined and the methods of combination.

**Chapter 36 Reliability Prediction**

Reliability Prediction has been the subject of much discussion in recent years. This chapter presents a balanced view of the arguments such that the reader can decide on the applicability for a given application. The chapter also emphasizes appropriate use of the results and address the misunderstandings held by many engineers and engineering managers.

**Chapter 37 Maintainability Prediction**

Maintainability Prediction has not been discussed as vociferously as Reliability Prediction mainly due to its lower prominence. However a similar approach is appropriate with an emphasis on the understanding of the meaning and usefulness of the results.

**Chapter 38 Markov Modelling**

Markov Modelling is a useful technique for the analysis of more difficult situations and the determination of generic results (such as those in Part D Chapter 6). This chapter presents the method.

**Chapter 39 Availability Demonstration**

Demonstration, here, is the practical determination of the truth of a hypothesis. In this case that the availability is greater than a certain value with a given level of confidence. This chapter addresses the way of designing and carrying out such a demonstration

**Chapter 40 Reliability Demonstration**

As for availability but substituting reliability.

**Chapter 41 Maintainability Demonstration**

As for availability but substituting maintainability.

**Chapter 42 Testability Demonstration**

As for availability but substituting testability.

**Chapter 43 Assurance Through the R&M Case**

This chapter presents an overview of the R&M Case with reference to the Def-Stan and ways of satisfying the requirements.

**Chapter 44 Production Reliability Acceptance Testing**

This chapter discusses the techniques applicable to testing the reliability through the production run.

**Chapter 45 Environmental Stress Screening**

This chapter addresses the benefits of ESS and the ways of generating and carrying out an effective programme.

**Chapter 46 Data Classification**

This chapter provides background and discussion on the implementation of the Defence Standard.

**Chapter 47 In-Service Data Collection**

The uses and benefits of collection are stressed in this chapter while addressing the available methods. CuSum is one technique addressed under this chapter.

**Chapter 48 Monitor/Control of Subcontractors/Suppliers**

In most systems the prime contractor contracts out much of the work to sub-contractors. The extent to which the main contract requirements for R&M should be passed through and the extent to which an allocation process should be carried out is addressed for different situations in this chapter.

**Chapter 49 R&M Plans & Programmes**

R&M Plans & Programmes are an important element of managing for the achievement of R&M. This chapter looks at the similarities and differences of R&M Plans to other project plans and explores why separate plans are often required. The provision of R&M procedures within an organization is also discussed.

**Chapter 50 R&M Data Storage**

Data storage is central to the long term improvement of R&M for specific systems and systems in general. This chapter looks at the types of data to be stored, the degree of detail required and the period of time for which data remains valid.

**Chapter 51 Software Reliability Techniques**

This chapter contains guidance on the two complementary approaches to the achievement of software reliability at the design and implementation phase; Fault Avoidance and Fault Tolerance. Fault avoidance requires taking steps to avoid faults during software development, and to detect and correct those faults that do occur. Fault tolerance requires designing software to correct or tolerate errors in service.

**Chapter 52 Software Reliability Evaluation**

This chapter describes the methods that can be adopted to evaluate the software reliability that has actually been achieved, including evidence from testing, field data, fault data and analytical arguments.

**Chapter 53 Fishbone Analysis**

Fishbone analysis is a form of cause and effect analysis and is used to explore the causes of a singe effect. The fishbone diagram enables the relationships and hierarchy of events to be arranged and depicted in a logical order proving a means for their relative importance to be conveniently compared.

**Chapter 54 BIT Effectiveness Analysis**

BIT effectiveness analysis is a form of testability analysis that embraces the relative virtue and outcomes (effects) of two or more courses of action. Bit effectiveness analysis is commonly used in the fields of electronic and system engineering where it may be inappropriate or impractical to practically determine the effectiveness of BIT under all system conditions particularly when that system is a subset of a much larger host system or whose interfaces and/or functionality may change subject to application.

## Part D Supporting Theory

Underlying the techniques described above is a substantial level of theory. This is best presented in its own right to avoid detail and duplication in the technique chapters.

**Chapter 1 Boolean Algebra**

This chapter explains the basics of Boolean algebra.

**Chapter 2 Bayesian Statistics**

This chapter identifies differences in applying Bayesian statistics against applying classical statistics and comments on the main areas of application in R&M work.

**Chapter 3 Statistical Distributions**

This chapter presents an overview of statistical distributions and summaries of the distributions mainly used in R&M work.

**Chapter 4 Monte-Carlo Simulation**

Monte-Carlo simulation is useful for determining quantified information from complex probabalistic models. This chapter explains the basic approach.

**Chapter 5 Pareto Analysis**

Pareto analysis provides a means of presenting the comparison of data relating to different options or categories. The application and benefits are discussed in this chapter.

**Chapter 6 Probabilistic R&M Parameters and Redundancy Calculations**

This chapter provides a basic introduction to the range of R&M parameters available and the applicable arithmetic.

**Chapter 7 Test Results Analysis, Parameter Estimation, Confidence Intervals & Hypothesis Testing**

This chapter provides an introduction to the mathematical theory behind the treatment of test results.

**Chapter 8 Reliability Growth Models**

This chapter supports Part C Chapter 15 through a discussion of available models and their foundation and application.

**Chapter 9 Availability Demonstration Plans**

This chapter supports Part C Chapter 39 through a discussion of available plans and generation of plans to specific parameters.

**Chapter 10 Reliability Demonstration Plans**

This chapter supports Part C Chapter 40 through a discussion of available plans and generation of plans to specific parameters.

**Chapter 11 Maintainability Demonstration Plans**

This chapter supports Part C Chapter 41 through a discussion of available plans and generation of plans to specific parameters.

## Part E R&M Management Techniques

The processes and techniques employed in R&M Engineering are only as good as the management structure supporting them. Appropriate R&M Management will enable effective use of resources while optimising time and expenditure. This section provides guidance on the R&M Management techniques available.

**Chapter 1 Reliability and Maintainability Panels and Working Groups**

R&M does not just happen it requires the development of an understanding of the Capability Requirement to enable risks associated with R&M to be mitigated through the generation of informed R&M programme. The R&M Panel (stakeholder group) enable interested stakeholders and subject matter experts to provide such timely support, advice and guidance.

## Part F Engineering for R&M

Engineering for R&M optimises Capability and in turn the cost of ownership by the cost effective improvement of reliability with the optimisation of maintenance intervention. This section provides guidance on the techniques available.

## Part G Miscellaneous

This section compliments Parts 1 to 6 by providing a number of useful leaflets, templates, terms of reference and other documents and papers to encourage and enable the successful management of R&M acquisition and development programmes.

## Leaflets

### Leaflet 1 The Case for R&M

An argument for developing and presenting evidence to build confidence in the level of system R&M.

### Leaflet 2 Aide Memoir for R&M Focal Points

This leaflet provides R&M Focal Points with guidelines on how to review frequently encountered R&M documents produced in support of R&M Case, R&M Case Reports or part of an R&M Programme.

### Leaflet 3 R&M Engineering Standards

A preferred list of R&M standard, compiled by CoDERM, which are in regular use by the MOD and its partners in Industry.

### Leaflet 4 The Importance of Maintainability in Achieving Operational Availability

The retention of equipment in a state to deliver a capability on demand doesn't just happen; it requires preparation and planning beforehand. This guidance discusses the drivers for the optimisation of the maintainability aspects of this preparation.

### Leaflet 5 Contracting for Availability

Contracting for Availability is a commercial process which seeks to sustain a system or capability for a given period of time at an agreed level of readiness. This guide addresses the significant issues relating to R&M which should be considered during the Contacting for Availability process and addressed by Availability Contracts.