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RELIABILITY AND MAINTAINABILITY ASSURANCE GUIDES

PART 2: SOFTWARE

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Arrangement of Defence Standard 00-42

The proposed arrangement of the complete series of Parts of Defence Standard 00-42 is:

Part 1- One-Shot Devices and One-Shot Systems

Part 2- Software

NOTE: Other Parts may be added to Defence Standard 00-42 as required.

RELIABILITY AND MAINTAINABILITY ASSURANCE GUIDES

PART 2: SOFTWARE RELIABILITY

PREFACE

i This Standard provides guidance on accommodating Ministry of Defence (MOD) reliability practices, procedures and requirements in the design process.

ii This Part of the Standard addresses the achievement of software reliability.

iii This Part of the Standard has been prepared by the Committee for Defence Equipment Reliability and Maintainability (CODERM). It reflects the conclusions of consultations among various authorities within the MOD and within industry.

iv This Standard has been agreed by the authorities concerned with its use and is intended to be used whenever relevant in all future designs, contracts, orders etc and whenever practicable by amendment to those already in existence. If any difficulty arises which prevents application of this Defence Standard, the Directorate of Standardization shall be informed so that a remedy may be sought.

v Any enquiries regarding this Standard in relation to an invitation to tender or a contract in which it is incorporated are to be addressed to the responsible technical or supervising authority named in the invitation to tender or contract.

vi This Standard has been devised for the use of the Crown and its contractors in the execution of contracts for the Crown. The Crown hereby excludes all liability (other than liability for death or personal injury) whatsoever and howsoever arising (including, but without limitation, negligence on the part of the Crown its servants or agents) for any loss or damage however caused where the Standard is used for any other purpose.

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RELIABILITY AND MAINTAINABILITY ASSURANCE GUIDES

PART 2: SOFTWARE RELIABILITY

Section One. General

0 Introduction

0.1 Def Stan 00-40 implements Allied Reliability and Maintainability Publication (ARMP- 1) and lists specific R&M tasks which form part of the design and development programme. The requirements of Def Stan 00-40, in whole or in part, can be made contractual during the design and development stages.

0.2 Def Stan 00-41: MOD Guide to Practices and Procedures describes the ARMP- 1 tasks in greater detail and adds supplementary material regarding tasks not listed in ARMP- 1.

0.3 Def Stan 00-42 is grouped under the general title of “Assurance Guides” and provides further guidance on MOD reliability practices, procedures and requirements in the design process.

0.4 This Part of Def Stan 00-42 is concerned with software, including ASICs and COTS software. It provides guidance beyond Def Stan 00-41 on the practices and procedures that should be adopted for assuring that any system that contains software achieves its required reliability. It aims to support the needs of Contractors, MOD Project Managers and End Users.

0.5 In respect of software maintainability, guidance maybe obtained by reference to Def Stan 00-60 Part 3: Logistic Support Analysis for Software. The latter expresses MOD policy for the maintenance and support of software and describes the factors that affect the supportability of software products, including elements in the development process.

0.6 The philosophy embraced is one of improving system reliability by early defect removal and continued defect prevention through the software development life-cycle. Visibility of reliability achievement is enforced through critical examination of the intellectual products of development. Because of extreme difficulties in making quantitative predictions for software reliability, credence is given to indirect measurements and assessments of correctness. Direct measures of software reliability achievement are made during full system testing, or based on analysis or field experience. Additionally this Standard enables and seeks to encourage the development and application of new techniques to assist with evaluation throughout the software life-cycle.

0.7 The guidance is built around two key components: the Software Reliability Plan and the Software Reliability Case. The plan addresses the software aspects of the system reliability plan, and describes the activities that are to be undertaken to achieve and demonstrate

0.7 (Contd)

software reliability. The case provides a justification of the approach, and during the project it documents the evidence that verifies that the software meets the reliability requirements.

0.8 The guide makes an important distinction between achievement and evaluation of software reliability. The Contractor should apply a software engineering process that gives a good likelihood of achieving software reliability requirements. However, the process used does not ensure that reliability requirements will be met for particular software products, and therefore the Contractor should evaluate the reliability of the evolving software products at each development phase.

0.9 The concept of the plan and case should enable innovation, and therefore the guide attempts to be general, with no preference for specific methodologies. However, a bibliography of appropriate standards and technical references is provided.

0.10 The guide is structured as follows. Section Two provides a summary of the principles of the plan and case, and is intended particularly for project managers. Section Three provides guidance on the plan and the case for the Procurer's and Contractor's technical staff. Detailed technical material is contained in the annexes.

1 Scope

1.1 This Standard provides a framework for the management of software reliability within system reliability requirements, based around the Software Reliability Plan and Software Reliability Case. It emphasizes the importance of evaluating progress towards meeting software reliability requirements throughout the project life-cycle.

1.2 This Standard applies to all projects that incorporate software, including the integration of previously developed software and COTS software products as well as bespoke developments. This Standard applies to conventional employment of software and to software associated with ASICs and programmable hardware.

1.3 This Standard does not describe software development practices in detail. However, references are provided to standards and other sources of further information.

2 WARNING

This Defence Standard embodies procedures, techniques, practices and tools which when followed or used correctly will reduce but not necessarily eliminate the probability that the product will contain faults which are attributable to software. The standard in no way absolves either the designer, the producer, the supplier or the user from statutory and all other legal obligations relating to health and safety at any stage.

3 Related Documents

3.1 The following documents and publications are referred to in this Standard:

ANSI/IEEE 610.12	Glossary of Software Engineering Terminology
BS 5760 (Part 8)	Guide to Assessment of Reliability of Systems Containing Software
Def Stan 00-13	Requirements for the Achievement of Testability in Electronic and Allied Equipment
Def Stan 00-40 (Part 2) (ARMP-2)	Reliability and Maintainability. Part 2: General Application Guidance on the Use of Part 1
Def Stan 00-41	Reliability and Maintainability, MOD Guide to Practices and Procedures
Def Stan 00-44	Reliability and Maintainability Data Collection and Classification
Def Stan 00-49	Reliability and Maintainability, MOD guide to Terminology Definitions
Def Stan 00-55	Requirements for Safety Related Software in Defence Equipment
Def Stan 00-56	Safety Management Requirements for Defence Systems
Def Stan 00-60 (Part 3)	Integrated Logistic Support. Part 3: Guidance for Application of Software support
Def Stan 05-91	Quality System Requirements for Design/Development, Production, Installation and Servicing.
Def Stan 05-95	Quality System Requirements for the Design/Development, Supply and Maintenance of software

3.2 Reference in this Part of the Standard to any related documents means, in any invitation to tender or contract, the edition and all amendments current at the date of such tender or contract unless a specific edition is indicated.

3.3 Related documents may be obtained from:

DOCUMENT	SOURCE
Allied Reliability and Maintainability Publication (ARMP)	Directorate of Standardization (Stan 2) Kentigern House 65 Brown Street Glasgow G2 8EX
British Standards (BS)	British Standards Institution Sales Department 389 Chiswick High Road London W4 4AL

3.3 (Contd)

DOCUMENT	SOURCE
Defence Standards (Def Stan)	Directorate of Standardization (Stan 1) Kentigern House 65 Brown Street Glasgow G2 8EX
American National Standards Institute (ANSI)/Institute of Electrical & Electronics Engineers (IEEE)	Technical Indexes Willoughby Road Bracknell Berks RG12 4DW

3.4 A bibliography of publications containing further technical information on the methods and techniques discussed in this Standard is provided at Annex J.

4 Definitions

4.1 The following special terms are used in this Part of the Standard. The definition of terms not given below should follow Def Stan 00-49 and ANSI/IEEE 610.12 where possible; otherwise normal English usage should be assumed.

4.2 Animation. The process by which the behaviour defined by a formal method or other specification notation is examined and validated against the informal requirements.

4.3 ASIC. Application-Specific Integrated Circuit.

4.4 BIT. Built-in-test. Used in this Standard to refer to the use of software for automatic fault detection and fault isolation. See also Def Stan 00-13.

4.5 Controlled failure. A failure that is handled by entering some defined degraded or fail safe state. The ability to control failures depends on the fail soft or fail safe strategy of the design and the nature of the application. See also Figure 2.

4.6 COTS software. Commercial off-the-shelf software, ie commercial software that is used without modification (apart from configuration) in the system.

4.7 Derived requirements. Software requirements that evolve during the course of the software development life-cycle. Examples are failure reporting and handling requirements following from the decision to write defensive code; and specific timing and capacity requirements resulting from the choice of a particular microprocessor and memory unit.

4.8 Design Review. A formal review of a software development project, including the software design and the Software Reliability Case, to establish that the software meets its requirements, including reliability requirements.

4.9 Error. A system state, resulting from a fault or human mistake, that is liable to lead to a failure if the error is not detected and corrected.

4.10 Error recovery. The correction of an error before it results in a failure, enabling the software to make a transition back to correct operation or to a defined state. Error recovery depends on the effectiveness of the error detection and recovery measures in the design (see Figure 2).

4.11 Failure. The inability of software to fulfil its operational requirements.

4.12 Fault. An imperfection or deficiency in the software that may, under some operational conditions, contribute to a failure.

4.13 Fault activation. The transition to an error from correct operation (see Figure 2). The probability of this transition depends on the number of faults and their size and distribution relative to the inputs to the software (which will depend on the way it is used), and is addressed by fault avoidance measures during development.

4.14 Formal method. A software specification and development method, based on a mathematical system, that comprises: a collection of mathematical notations addressing the specification, design and development phases of software production; a well-founded logical inference system in which formal verification proofs and proofs of other properties can be formulated; and a methodological framework within which software may be developed from the specification in a formally verifiable manner.

4.15 Procurement Specification. The most detailed specification of the system produced by the Purchaser’s organisation, and the basis for the contract with the Contractor. Developed from the Cardinal Points Specification and the Staff Requirement, possibly with the aid of a feasibility study.

4.16 Requirements engineering. The activities that lead to the production of the Purchaser’s requirements, including requirements capture, definition, analysis and the development of derived requirements.

4.17 Software component. One of the parts that make up a software system. A software component may be a module, a unit or a larger structure depending on the stage of development.

4.18 Software fault density. The number of faults in a given amount of software. Faults per thousand non-blank, non-comment lines of code is a common measure.

4.19 Software product. All the manifestations of software that exist at a particular phase in the development life-cycle, such as specifications, designs, source code and executable code.

4.20 Software engineering process. The application of technical and managerial methods, techniques and tools by a team of people to produce a software product from the Purchaser's requirements. Elements of the software engineering process may include specification, design, coding, testing and reviewing.

4.21 Statistical testing. Testing using data representative of the actual operating environment, to an extent that gives a statistical estimate of reliability. Statistical testing will probably be carried out at the system level.

4.22 Uncontrolled failure. A failure where no error recovery or controlled failure is carried out. The impact of this will depend on the criticality of the system functions affected (see Figure 2).

4.23 V&V. Verification and validation. ANSI/IEEE 610.12 provides further information.

Section Two. Principles of the Software Reliability Plan and the Software Reliability Case

5 Introduction to the Plan and the Case

5.1 The Software Reliability Plan and the Software Reliability Case are the two key documents supporting the achievement of software reliability. The plan addresses the software-specific management and technical tasks that are to take place within the overall reliability programme, including collecting evidence of reliability achievement, and maintaining the case. The case develops during the project and documents the evidence and arguments for software reliability achievement. It also contains a justification of the software engineering process and the software architecture.

5.2 The Purchaser may require the Software Reliability Plan and the Software Reliability Case as deliverable items in the contract. Also, the Purchaser may require a plan and a tender-stage case at the tender or pre-contract stages of the project. Further issues of the case should take place at project milestones and may be linked to the payment plan.

5.3 Guidance on developing the Software Reliability Plan and the Software Reliability Case is contained in Section Three.

6 Principles of the Software Reliability Plan

6.1 The Software Reliability Plan is the plan for the management and technical activities that bear on the achievement of software reliability, including the maintenance and updating of the Software Reliability Case. It should be traceable to system reliability planning and to avoid unnecessary replication, should be integrated with software development and quality management planning.

6.2 The Software Reliability Plan should describe:

(a) The software reliability requirements, derived from the system reliability requirements;

(b) The software engineering process, addressing:

(i) the development life-cycle, including: its constituent processes and tasks; the relationship between the tasks in terms of their inputs, outputs and scheduling; planned completion dates; and dependencies on other products and activities;

(ii) the techniques to be used for software requirements analysis and review;

(iii) the techniques, methods and tools to be used for software production, verification and validation at each life-cycle phase;

(iv) any support tools to be used, including automated configuration management and database support for records and data;

6.2 (Contd)

(v) the documented procedures to be used, including the Contractor's in-house procedures, national and international standards;

(vi) the identification, selection and integration of COTS and previously developed software.

(c) The techniques, methods and tools to be used for the evaluation of the achieved software reliability at each life-cycle phase;

(d) Project risk analysis for the software;

(e) The organisational structure, including:

(i) the individuals and organisations involved in software development, including subcontractors;

(ii) the identification of key posts, with a description of minimum levels of competence;

(iii) the means by which all staff, including subcontractors, are made aware of the software reliability requirements and their specific responsibilities;

(iv) any training activities and requirements.

(f) The procedures for software reliability progress reporting, including:

(i) the phased updating of the Software Reliability Case;

(ii) the phasing of Design Reviews.

(g) other documentation and data to be delivered.

6.3 The plan should make reference to the Statement of Work for the software development, containing details of the manpower and resource requirements, and how they are to be met.

7 Principles of the Software Reliability Case

7.1 The Software Reliability Case should be a readable overview of the evidence that the software meets its reliability requirements, with references to project development records and the results of analyses of software components as appropriate. The case is more than proof that the plan has been executed as it provides evidence about intellectual products. This evidence should address the direct evaluation of the reliability of the software products (eg from reliability tests and trials and analysis of the design), and also the suitability of the software architecture and the software engineering process.

7.2 The case should be a living document and its development should proceed through a number of stages of increasing detail during the project. At the beginning of a project it should provide confidence, before committing significant resources, that there is minimal risk of failing to meet the reliability requirements; during the development stage it should provide confidence that the reliability requirements are being met by the software products; and during use of the system it should provide confidence that the software is reliable and continues to be so as the result of any maintenance.

7.3 The development of the Software Reliability Case takes place in identifiable phases:

(a) Tender-stage Software Reliability Case; which can form part of any proposal in order to justify design and process decisions upon which the proposal is based.

(b) Development-stage Software Reliability Case; which can be a contracted deliverable, phased as appropriate.

(c) In-service Software Reliability Case; which can be a contracted deliverable, considered at an early stage or negotiated at a later date.

7.4 Tender-stage Software Reliability Case

7.4.1 The Tender-stage Software Reliability Case should provide an overview and analysis of the Contractor's approach to reliability achievement. It should give confidence that:

(a) the Contractor is capable of supplying software that is commensurate with the reliability requirements of the proposed system;

(b) the plan is appropriate for the reliability requirements of the proposed system;

(c) the software architecture is appropriate for the reliability requirements of the proposed system;

(d) the Contractor will be able to demonstrate reliability achievement during the project.

7.5 Development-stage Software Reliability Case

7.5.1 During development, the Contractor should update the case with a summary and appraisal of the results of the activities that contribute to the reliability evaluation. By the time of acceptance into service, the case should contain the complete set of evidence that the reliability requirements of the software have been met.

7.5.2 The Purchaser and the Contractor should agree in advance the measurements, including reliability tests and trials, to be taken of the software products and the software engineering process to provide evidence that the development is proceeding satisfactorily. These measurements should be described in the case; earlier versions of the case should predict

7.5.2 (Contd)

values for these measurements that the Purchaser can compare to the results actually obtained later in the life-cycle.

7.5.3 Issues of the case should be planned for appropriate milestones in the software development life-cycle, for instance after reliability tests and trials. The current version of the case should be presented at each Design Review (see Annex D), and the outcome included in the case.

7.6 In-service Software Reliability Case

7.6.1 The Purchaser should consider employing in-service software reliability management. This includes the collection of operational and usage data and the maintenance of an In-service Software Reliability Case. The case should contain a description of the field experience with the software or any part of it, and an analysis of the impact of any software failures on the reliability of the system, addressing the potential consequences of the failure, its root causes, and the lessons for the software engineering process.

7.6.2 An In-service Case can be justified when reliability remains uncertain after a decision to employ the software in question, either because of continuing development or inadequate evidence of reliability achievement during development.

7.6.3 In-service reliability data can be used for:

(a) reviewing or confirming reliability achievement;

(b) determining reliability when software is used in a new environment;

(c) gathering experience on the performance of particular methods, techniques and processes for the benefit of future projects and development organisations which operate within a process improvement framework.

7.6.4 Options for employing an In-service Software Reliability Case, including responsibilities and procedures for managing reliability data should be considered during contract negotiations.

Section Three. Production and Assessment of the Software Reliability Plan and Software Reliability Case

8 Introduction to Section

8.1 This section provides general guidance aimed at the production and assessment of the Software Reliability Plan and Software Reliability Case. More detailed technical information is contained in the annexes. An index to the specific methods and techniques described in the annexes is provided at Annex A, with a summary of how each method and technique contributes to the case. A bibliography of reference material is provided at Annex J.

8.2 The Contractor should ensure that the Software Reliability Plan and Software Reliability Case are integral parts of the software design and development methodology, and should evaluate at the tender stage the feasibility and cost of implementing the plan and maintaining the case.

8.3 The software should be designed to facilitate production of the Software Reliability Case. Both the achievement and demonstration of software reliability should be design drivers. This should help to avoid delays and additional costs for the Contractor due to software reliability problems.

9 Software Reliability Planning

9.1 The Software Reliability Plan

Planning for software reliability should be an integral part of project planning. Therefore the Software Reliability Plan may be integrated with the software development plan and/or the software quality plan, provided that the measures to achieve and evaluate software reliability are easily distinguishable. Traceability should be provided between the plan and the overall Reliability Programme Plan.

9.2 Software reliability planning activities

9.2.1 Software reliability planning should, as a minimum, include the following activities:

(a) allocating reliability requirements to software;

(b) defining the strategy for software reliability achievement;

(c) defining the strategy for evaluating achieved software reliability.

These activities are not sequential, but are interlinked and iterative.

9.2.2 An adequate software engineering process is necessary but not sufficient for the achievement of software reliability. A defined process is necessary to ensure that appropriate methods and techniques are carried out at the correct point in the development, to enforce

9.2.2 (Contd)

configuration control, and to enable adequate management of the project. However, the process does not in itself allow predictions or demonstrations of software reliability to be made. Software reliability evaluation, to provide assurance that the software products as built meet their reliability requirements, should be planned for as a specific activity.

9.3 Allocation of reliability requirements to software

9.3.1 Software components may be identified at various levels in a system breakdown, and may be implemented in a number of ways, including application software, firmware, COTS and ASICs The Contractor should allocate system reliability requirements to the software components as an initial step in software reliability planning. This enables activities to be planned on the basis of their ability to achieve and demonstrate the specific software reliability requirements.

9.3.2 More detailed guidance on software reliability allocation is contained in Annex B.

9.4 Strategy for software reliability achievement

The Contractor should plan a software engineering process that gives a good likelihood that the developed software will meet its reliability requirements. The plan should include:

(a) software requirements engineering to ensure that the needs of the Procurer are fully understood (see Annex E);

(b) the application of appropriate techniques and methods for software specification, design and implementation, selected on the basis of the reliability requirements and the Contractor's experience (see Annex F);

(c) any detailed planning activities that should take place prior to application of each method or technique;

(d) development and review of test plans at the software specification phase.

9.5 Evaluation of achieved software reliability

9.5.1 The Contractor should plan to provide direct evidence of the reliability of the developing software products throughout the project.

9.5.2 As explained in Annex G, direct evidence of software reliability can come from:

(a) testing;

(b) field data;

9.5.2 (Contd)

(c) fault data;

(d) analytical arguments,

9.5.3 In general, different types of evidence will be used to address different aspects of the reliability requirements for the software. Reliability evaluation of software with stringent reliability requirements is especially difficult and in this case the Contractor should plan to provide diverse forms of evidence to cover each aspect of software reliability. The final arbiter will be testing at system level.

10 The Software Reliability Case

This clause provides guidance on the way the Software Reliability Case should be structured and linked to the fault avoidance and fault tolerance strategy of the plan, the way in which reliability demonstration should be documented, and on the contents of the case at the tender, development, and in-service stages.

10.1 Structuring the Software Reliability Case

10.1.1 A Software Reliability Case is an assembled rationale which would be convincing to a third party and primarily consists of the following elements:

(a) a claim, about a property of the software;

(b) evidence and assumptions, which are used to support the reliability claim (see **9.5);**

(c) an argument linking the evidence to the claim.

This structure is illustrated in Figure 1

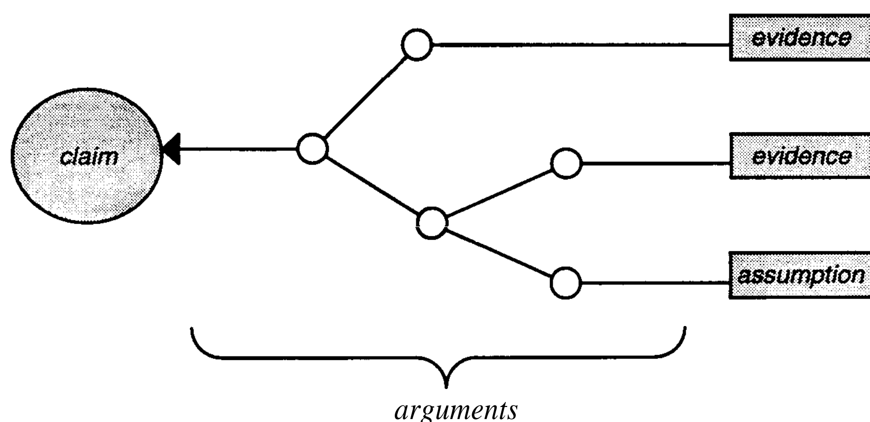

Figure 1 Elements of a Reliability Argument

10.1.2 As an example, a claim could be a statement that a software component meets its allocated reliability target; the evidence could come from testing; and the argument could be based on statistical analysis.

10.1.3 The case will normally be presented as a hierarchical structure, with top-level claims decomposed into sub-claims appropriate for the architecture of the system and software. This structure should evolve over the lifetime of the project. Initially some of the sub-claims will be design targets, but as the system develops, the sub-claims will be replaced by facts or more detailed arguments based on the actual implementation. Deviations from earlier versions of the case should be analysed for their impact on the claims and sub-claims.

10.2 Strategy for fault avoidance and fault tolerance

10.2.1 The Contractor should develop a strategy for minimizing software faults, and for controlling system failures due to any residual software faults.

10.2.2 Figure 2 is one way of illustrating the transitions that may occur between correctly functioning software and a failure state. The overall reliability of the software will depend on the probability of each of these transitions, and the case should describe how each is to be addressed. Different transitions may be controlled in different ways and given different emphasis; for example, in one application the emphasis could be on error recovery by means of fault-tolerant architectures, whereas in another the concentration might be on error avoidance by means of structured design methods and static analysis. Different components (eg COTS and bespoke software) may also be treated differently.

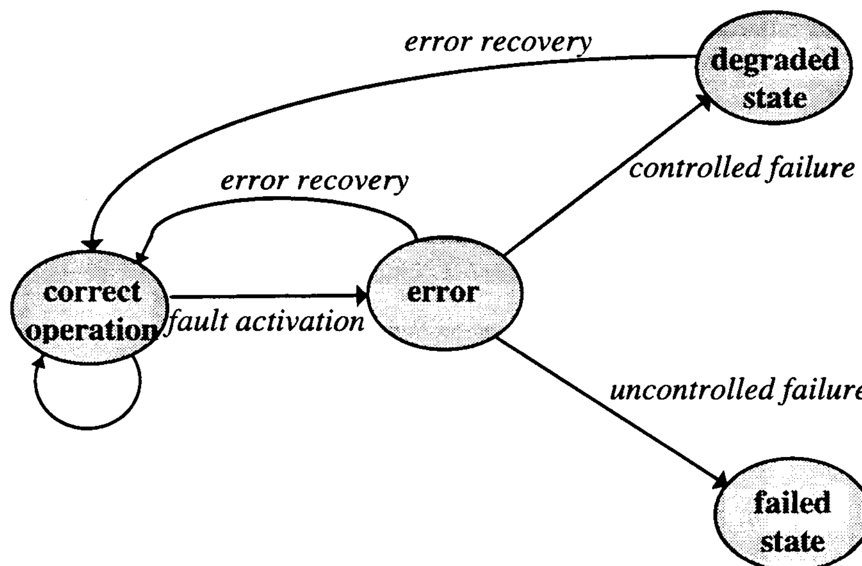

Figure 2 Transitions to a Software Failure State

10.3 Demonstration of software reliability achievement

10.3.1 Demonstration of software reliability achievement is a key part of the case and is obtained from two sorts of evidence:

(a) direct evaluation of the achieved reliability of the software products;

(b) evidence of the general suitability of the software engineering process.

This evidence should be documented in the case as it is accumulated.

10.3.2 Direct evaluation of achieved software reliability. The case should address the planned means for the direct evaluation of the reliability of the software products, as described in **9.5.** It should provide:

(a) An overview of the reliability evaluation tasks, explaining how they demonstrate that the reliability requirements have been met, and describing how evidence of reliability achievement can be accumulated during the project. This should include as appropriate:

(i) the feasibility of collecting sufficient quantities and quality of data for reliability evaluation from reliability growth modelling, fault data and/or field experience;

(ii) the resources needed for statistical testing, and the feasibility of providing justifiable operational profiles for the system taking into account the uncertainties of equipment deployment;

(iii) a description of the approaches to be used for providing analytical arguments, and an assessment of their feasibility in view of the estimated software size.

(b) A structured summary and overview of the evidence as it is collected during the project, with reference to detailed results as appropriate. This may include:

(i) evidence from testing, including reliability growth modelling, statistical testing, data from tests and trials, and performance testing, with an assessment of its accuracy and relevance to operational use;

(ii) a description of any claims made on the basis of previous in-service experience, including an analysis of the similarities and differences between the actual system and environment and those to which the experience relates;

(iii) evidence from fault data on the software;

(iv) the results of any analytic arguments deployed to show the absence of certain faults, and the assumptions on which they are based.

10.3.2 (Contd)

(v) an overview of any ASICs COTS or previously developed software that is to be used, and a description of the way in which it will contribute to software reliability, taking into account any changes in operating environment and use profile (see **11** and **12).**

Technical guidance on software reliability evaluation is given in Annex G.

10.3.3 General suitability of the software engineering process. The case should contain an overview of the software engineering process that explains how it is appropriate for the reliability requirements for the software (see **9.4).** Items that might be included are:

(a) An analysis of the methods, techniques and procedures to be used, with an assessment of their suitability for the reliability requirements, including:

(i) a description of the generic types of software fault that will be specifically addressed and minimized;

(ii) an analysis of reliability data on other software developed using the proposed or similar methods, techniques and processes (sources of these data include the Contractor's own records and the published literature);

(iii) a justification of the choice of tools and support software, with a description of the way in which known problems (eg compiler faults) are to be handled and recorded.

(b) A description of how reliability progress is to be measured. This should include:

(i) any measurements that are to be taken (eg as part of inspections) during the software development life-cycle of the performance of the software engineering process (suitable measures are discussed in Annex F);

(ii) the verification and validation test strategy, including the test coverage to be achieved and the means for generating the tests.

The case should include acceptance criteria for these measures, based on previous experience with the software engineering process. During development, these data should be recorded in the case and compared with the acceptance criteria. The corrective action to be taken if the acceptance criteria are not met should be described.

(c) Confirmation that the minimum levels of personnel competency defined in the plan have been achieved.

10.4 Tender-stage Software Reliability Case

10.4.1 The Tender-stage Software Reliability Case provides an overview and analysis of the Contractor's approach to reliability achievement and evaluation at the pre-contract or tender stage. Items that might be included are:

(a) A description of software at an appropriate level of detail, including the main functions, the consequences of failure, and the environment in which it will be used.

(b) A description of the proposed software architecture and the way in which it is appropriate to system reliability requirements, including:

(i) the allocation of reliability to the software components (see Annex B);

(ii) the design strategy for fault avoidance and fault tolerance (eg for internal errors, external failures and overload conditions) adopted to meet the reliability requirements (see **10.2),** with an overview of the trade-offs made and any architectures that were considered but rejected;

(iii) the role of the software in achieving system reliability (eg by implementing BIT functions - see Def Stan 00-13);

(iv) any hardware monitoring of the software (eg by means of watchdogs), with a discussion of the coverage of failures;

(v) the means used to prevent failures propagating (eg software partitioning, hardware memory protection, etc.).

(c) An overview of the software engineering process, as described in **10.3.3.**

(d) A description and explanation of the way in which software reliability evaluation is to be carried out through the life-cycle, as described in **10.3.2(a).**

(e) As part of project risk analysis, an assessment of any specific risks associated with meeting the software reliability requirements within the project timescales and budget, where possible by reference to similar systems.

10.5 Development-stage Software Reliability Case

10.5.1 During the development stage, the case should accumulate the evidence that reliability achievement is proceeding satisfactorily. This evidence should include activities carried out early in the development, such as inspections of specifications and analysis of designs for performance attributes, as well as those carried out later, such as testing on a simulator. The case may include:

(a) Data about the development, such as fault density measures and the results of inspections of specifications, designs and code (see Annex F). The way in which this evidence shows that

10.5.1 (Contd)

the development is likely to meet its reliability requirements should be described. Earlier versions of the case should predict values for these data; later versions should compare the predictions with the actual evidence, discuss the reasons for any differences and propose changes to improve the accuracy of the predictions.

(b) Data on the evaluation of achieved reliability as described in **10.3.2(b).** An assessment of the sensitivity of the overall software reliability evaluation to the individual pieces of evidence should be included.

(c) A statement of the software components (including specifications, design documents and software code) developed so far.

(d) A summary of changes from previous versions of the case with a statement of the reason for the change and an analysis of the significance and implications for software reliability.

(e) A description of any outstanding issues that may effect the reliability of the software, and a statement of progress with respect to the Software Reliability Plan.

(f) An analysis of the compliance with this Standard and any other standards or guidelines referenced in the Software Reliability Plan. A statement of any concessions that have been negotiated with the MOD Project Manager should be included.

(g) The software configuration and versions of hardware, tools and support software that this case refers to, defined by reference to the Software Configuration Management Plan.

(h) The outcome of the presentation of the case at the Design Reviews (see Annex D).

10.5.2 Amendments to the software requirements may have an impact on software reliability achievement. The case should state how the reliability requirements will continue to be met following such amendments, and describe any changes to the plan and case that are necessary.

10.6 In-service Software Reliability Case

10.6.1 In-service software reliability management includes the collection of operational and usage data and the maintenance of an In-service Software Reliability Case.

10.6.2 Data collection should be by an agreed means of in-service reporting mechanism. Def Stan 00-44 contains guidance on data reporting and classification; Part 2 addresses incident sentencing (see also BS 5760 Part 8).

10.6.3 In-service software reliability management may be supported by mechanisms which identify, diagnose and record internal failures. As the inclusion of such features is a development stage activity it is important that the need is given timely consideration. The data recorded may include:

10.6.3 (Contd)

(a) clear identification of the current software version and configuration;

(b) utilisation levels of resources;

(c) task execution states;

(d) errors detected at interfaces;

(e) anomalies detected by defensive software checks;

(f) operating modes (eg automatic, manual or degraded);

(g) key input and output data values.

10.6.4 It is important to justify the similarity between the applications used to gather in-service reliability data and any proposed new application (see **F.2.13.2).** The attributes to be considered may include:

(a) data rates;

(b) throughput;

(c) functions used;

(d) input ranges;

(e) resource usage (eg CPU time);

(f) configuration options (eg data conversion routines and thresholds);

(g) operational mode;

(h) accuracy;

(i) mission time.

11 COTS Software

11.1 Current trends are towards an increased use of commercial off-the-shelf (COTS) software and other forms of pre-existing software that may not have been originally designed for the Procurer's use. While this may reduce procurement costs, software reliability planning needs to address additional problems that may arise in the reliability evaluation of COTS

11.1 (Contd)

software. COTS software generally is not developed under the umbrella of a particular contract and there are few reliability targets or incentives to collect or provide information about reliability.

11.2 Some COTS may have benefited from reliability growth in service, as discussed in Annex F. However, commercial pressures to produce frequent upgrades of COTS software often mean that priority is given to providing new features rather than improving reliability.

11.3 One difficulty with COTS software is that it may not be possible to perform detailed testing or analysis based on knowledge of the design or code. This limitation implies that many of the current approaches to software evaluation are not applicable. Examination of development procedures, progress reports and test results should not be ruled out but it may be difficult to make procurement decisions based on the quality of the software production process because there is insufficient information.

11.4 Therefore, evaluation of the reliability of COTS software has generally to be undertaken by treating it is as a black box. Possible means are:

(a) functional testing (see Annex F);

(b) use of field data (see Annex G), taking into account differences in operating environment (see Annex F).

12 ASICs

The Software Reliability Plan and Software Reliability Case should explicitly consider any ASICs (Application-Specific Integrated Circuits) that are to be developed. Guidance on ASICs is given in Annex H.

13 Safety Critical Software

Development of safety critical and safety related software requires the development of a Software Safety Plan and a Software Safety Case, addressing the specific methods and activities to be adopted to achieve and evaluate safety. Details are contained in Def Stan 00-55 and Def Stan 00-56.

Table of Methods and Techniques

A.1 The annexes to this Standard contain technical guidance on the achievement and evaluation of software reliability. The table below contains an alphabetical index to the specific methods and techniques that are mentioned. It also indicates how each contributes to the Software Reliability Case by evaluating reliability and/or demonstrating the suitability of the software engineering process. The methods and techniques are described for the purposes of illustration, and the inclusion or omission of a particular method or technique does not indicate a preference by the MOD.

Technique	**Annex**	**Contribution to case**	
		Reliability evaluation	***Suitability of the process***
Analytical arguments	**G.5**	✓	
Checklists	**E.4.6**		✓ (fault avoidance and fault data)
Classification of requirements	**E.4.3**		✓ (fault avoidance in requirements)
Cleanroom	**F.2.11**	✓	✓ (fault avoidance)
Defensive programming	**F.3.2**		✓ (fault detection and handling)
Design maturity	**F.2.13**		✓ (use of components of proven reliability)
Design reviews	**Annex D**		✓ (fault avoidance and fault data)
Exhaustive testing	**G.5.3**	✓	
Fault tolerance	**F.3**		✓ (fault detection and handling)
Fault tolerance verification	**F.3.4**	✓	
Formal methods	**E.3.5, F.2.5**		✓ (fault avoidance and fault data)
High level programming languages	**F.2.8**		✓ (fault avoidance)
Human factors in software design	**F.2.12**		✓ (fault avoidance)
Inspections	**F.2.3**		✓ (fault avoidance and fault data)

Continued on page A-2

Technique	**Annex**	**Contribution to case**	
		Reliability evaluation	*Suitability of the process*
Language subsets	**F.2.8.3**		✓ (fault avoidance)
Measures (metrics)	**F.2.9**		✓ (fault data)
Object oriented methods	**F.2.8.2**		✓ (fault avoidance)
Performance testing	**G.2.3**	✓	
Prototyping	**E.4.8**		✓ (fault avoidance in requirements)
Reliability analysis	**F.2.6**		✓ (design for reliability)
Reliability estimation from fault data	**G.4**	✓	
Reliability growth modelling	**G.2.1**	✓	✓ (fault data)
Requirements inspections	**E.4.5**		✓ (fault avoidance in requirements)
Software diversity	**F.3.3**		✓ (fault detection and handling)
Specification notations	**E.3.4**		✓ (fault avoidance)
Static analysis	**F.2.7**		✓ (fault avoidance and fault data)
Statistical testing	**G.2.2**	✓	
Structured design	**F.2.4**		✓ (fault avoidance)
Subjective requirements evaluation	**E.4.7**		✓ (fault avoidance in requirements)
Testing	**F.2.10**	✓ (some types)	✓ (fault avoidance and fault data)
Traceability analysis	**E.4.4**		✓ (fault avoidance)
Use of field data	**G.3**	✓	

Allocation of Reliability to Software

B.1 Introduction

This annex provides guidance on the allocation of system reliability requirements to software.

B.2 Software Reliability Allocation

B.2.1 Software reliability requirements should be derived from the reliability requirements for the system by apportioning reliability to the software components of the system design, in the same way as to the hardware components, using techniques such as fault tree analysis and reliability block diagrams. Reliability apportionment should be carried out as described in Section Thirteen of Def Stan 00-41.

B.2.2 Measures for software reliability are discussed in BS 5760 Part 8. Where appropriate, separate software reliability requirements should be given for different types and consequences of failure. For example, a distinction might be made on the basis of

(a) the consequence of failure;

(b) whether or not recovery from a failure is possible without operator intervention;

(c) whether or not a failure causes corruption of software or data;

(d) the time taken to recover from a failure.

B.2.3 Validity of software reliability allocation

B.2.3.1 Software failures occur as a result of design faults. A program that fails once on a particular sequence of inputs will always fail on that sequence, given the same initial conditions, until the offending fault has been successfully removed. This systematic behaviour is sometimes thought to make it impossible to allocate reliability to software. However, it is as valid to allocate reliability to software as to hardware.

B.2.3.2 The reliability observed in hardware is dependent on the environment, stress factors (eg the number of power-on/power-off cycles), “hygiene factors” (eg quality of equipment earthing), and maintenance practices (eg precautions against electrostatic damage). Some of these factors could be regarded as systematic (eg poor maintenance and electrical stress), but reliability statistics lump together these unknown factors to derive an average failure rate. In addition, there are often design faults in complex hardware that are activated under specific input conditions. However, provided they fall below a certain frequency, they are tolerated in a similar way to any other failure.

B.2.3.3 The failure of a hardware component cannot be predicted exactly because its physical state and the environmental stresses that will be placed upon it during its lifetime are not known precisely, and the models of the hardware failure processes are not exact. In practice, statistical methods are used to cope with this uncertainty. Even then some allowance has to be made for the limiting effect of design-related failures rather than assuming that component failures are independent.

B.2.3.4 Software failures can be modelled by considering that software defects are at fixed places in the program input and state space (see Figure 3 in Annex F). A failure will occur if a certain input value is chosen in conjunction with a particular internal state, typical examples of internal state being counters, integration values and latches. For example, a control algorithm will have a different output depending on the integrated value of past control errors. Thus the probability of failure will depend on the chance of choosing an input value while the software is in a susceptible state. For many systems, particularly real-time systems, it is very difficult to replicate a failure precisely because it is difficult to replicate the exact internal state of the software.

B.2.3.5 If input values follow some statistical distribution, there will be an associated distribution of internal state values, and an associated "operational failure rate" for the software when averaged over time. Changing the input distribution could change the failure rate dramatically (eg the input values could strike far more defects, or far fewer). So the failure process is systematic, but the failure of a software component cannot be predicted exactly because the internal state and the environmental stresses are not known, and the model of the software failure process is inexact (the location of the faults is not known).

B.2.3.6 This is a virtually identical situation to that described above for hardware, as is illustrated in the following examples:

(a) a software control algorithm where the integral value can overflow resulting in an equipment control failure. Exact prediction of failure time is impossible because of uncertainty in the demands placed on the equipment, the time delays and errors introduced by the actuators and sensors, and the exact equipment response;

(b) a crack in a hardware component that will grow when stressed. Exact prediction of failure time is impossible because of uncertainty in the metallurgical properties and the likely stresses that will be imposed in the future.

B.2.3.7 It might also be argued that hardware exhibits more continuity when the conditions change, ie there is a monotonic relationship between stress and failure, so greater stress increases the probability of failure. However these relationships are also observed in complex software systems, which are subject to variable demands. Empirical studies have shown that software failure rates can increase by orders of magnitude under high stress conditions (eg high utilisation factors for the processor, disk and communications).

B.2.3.8 There is empirical evidence to support the quantification of software reliability. Some recent research is reported in the papers listed in **J.9.**

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Software Maintainability

Def Stan 00-41 (Part 2)/1 concentrates on software reliability and does not address software maintainability. Guidance on software maintainability may be obtained by reference to Defence Standard 00-60 Part 3 (Logistic Support Analysis for software). The latter expresses MOD policy for the maintenance and support of software and describes the factors that affect the supportability of software products, including elements in the development process.

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Design Reviews

D.1 Introduction

D1.1 It is to be expected that the Contractor will hold Design Reviews at intervals throughout the design and development of the software. Design Reviews are applicable to software at any stage in the project and at any level of detail and should include reliability aspects, specifically to ensure that, at the time of the review:

(a) the means for achievement and evaluation of software reliability requirements are being implemented in accordance with the Software Reliability Plan;

(b) The Software Reliability Case is being developed as planned.

D.2 Contribution to Reliability

D2.1 Design Reviews should be minuted in order to provide evidence for the Software Reliability Case.

D2.2 Specific reliability issues which should be addressed in design reviews include:

(a) suitability of the design for the system level reliability requirements;

(b) analysis of failure mechanisms and the means for their control;

(c) the ability to assess reliability achievement;

(d) analysis of information regarding COTS and other previously developed software which is to be integrated and the extent to which such information will be valid in the proposed application;

(e) forecasts of reliability performance.

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Requirements Engineering

E.1 Introduction

E.1.l Requirements engineering is a key part of software reliability achievement. Problems with the requirements are likely to propagate through to the design, increasing the risk of faults in the delivered system and the cost of correction.

E.1.2 This annex describes the activities that should be undertaken as part of requirements definition and analysis, including the production of the Procurement Specification and the development and analysis of the software requirements. More information on the methods and techniques discussed in this annex can be obtained from the publications listed in Annex J.

E.1.3 It is recognized that contractual arrangements vary greatly according to the nature of the procurement. On the one hand, the Purchaser may be developing requirements for a large system, for which software components will be developed by one or more subcontractors; on the other hand, the Purchaser may be procuring software directly. Where a complex contractual chain exists, there may be several procurement specifications, one produced by the Purchaser, one by the prime contractor, etc., and several software requirements specifications produced by different subcontractors. The guidance below should be applied as necessary to all specifications.

E.2 Definition of Purchaser's Requirements

E.2.1 Feasibility studies

E.2.1.1 At the early project phases, the Purchaser and Contractor should give attention to the possibility of achieving the overall reliability target, and whether it is practicable to produce and evaluate software to the likely reliability requirements, bearing in mind the cost and time budgets for the project. Existing software with similar reliability requirements should be identified and lessons learnt from its development where possible. The Purchaser may undertake feasibility studies to address how the evidence for software reliability attainment is to be obtained (eg from statistical testing, existing field experience, analytical arguments, or in-service reliability tests and trials). It may be beneficial to consider appropriate statements in the Procurement Specification to facilitate the evaluation and justification of reliability.

E.2.2 Procurement Specification

E.2.2.1 The Purchaser should address in the Procurement Specification the information that the Contractor or potential tenderers will need to prepare an effective Software Reliability Plan and Case. The Procurement Specification should include:

(a) Numerical reliability requirements for the system. These requirements should be realistic, and should distinguish critical functions;

E.2.2.1 (Contd)

(b) A statement of any degraded system modes or fail safe states that could be used as part of a fault tolerant strategy;

(c) A description of the conditions of use and operating environment.

E.2.2.2 If certain requirements are uncertain, complex or difficult to visualize at the feasibility or project definition life-cycle phases, it is likely to be cost-effective to plan for the production of a prototype (see **E.4.8).**

E.2.2.3 A route to reliable software is through simplicity and design maturity. If possible, the Procurement Specification should be developed in an evolutionary way from earlier successful projects, rather than be a radical departure.

E.2.2.4 Generally, the Contractor will apportion reliability to the software components of the design, but if some initial design work has been carried out (for instance by a feasibility contractor if appointed) to the extent that the software components have been identified, the Procurement Specification should give the software reliability requirements.

E.2.2.5 The Purchaser should hold a formal review of the Procurement Specification prior to release to the Contractor or potential tenderers to establish that the system reliability requirements and other fundamental requirements are complete and correct. Once the Procurement Specification is issued, amendments to it should not be made unless the project costs and timescales can be extended to accommodate the reworking of the reliability activities affected by the changes.

E.3 The Software Requirements Specification

E.3.1 The Contractor should develop a Software Requirements Specification from the Procurement Specification. It should be produced in accordance with an appropriate standard or guideline (see Annex J). Care should be taken to ensure that the requirements meet the user's needs, and each requirement should be traceable to an item in the Procurement Specification.

E.3.2 The requirements specification should include a statement of the numerical reliability goals for each identified software component, as discussed in Annex B.

E.3.3 The requirements specification should include derived requirements, ie software requirements that evolve during the course of the software development life-cycle.

E.3.4 Specification notations

E.3.4.1 The Contractor should consider using a notation designed to support requirements specification. Such notations contribute to reliability by avoiding the ambiguity and

E.3.4.1 (Contd)

inconsistency of natural language, and also allowing better structuring and traceability of requirements. Requirements specification notations include SADT, SSADM and CORE.

E.3.4.2 When choosing a special specification notation, the Contractor should consider how easy it will be for the Procurer to understand it. Problems can be avoided by:

(a) choosing a notation in which expertise exists in the Procurer's organisation;

(b) making provision for training the Procurer's staff in the notation to an appropriate level;

(c) providing a commentary on the requirements specification in English.

E.3.5 Formal methods

E.3.5.1 Formal methods are specification and development methods for software and hardware that have a rigorous mathematical basis. They can be used as specification and design notations, and also as a means of carrying out V&V by means of proof. They require highly-trained staff and are best applied selectively, eg to relatively small, critical systems, components or interfaces. They may also be cost-effective for complex real-time and concurrent systems, which are often impossible to reason about informally.

E.3.5.2 Formal methods assist in the achievement of software reliability in several ways:

(a) They provide a precise and unambiguous way of representing software specifications and designs, and force the specifier to address the details.

(b) They can be reasoned about mathematically, which enables them to be verified and validated much more thoroughly than is possible with an informal specification.

(c) They can often be executed directly, or after a single design step, which makes it easy to carry out prototyping.

(d) They provide a way of constructing analytical arguments about software, as discussed in **G.5.**

E.4 Requirements Analysis

E.4.1 Faults in the software requirements are often not detected until late in the project life-cycle, when they are very expensive to correct. Beginning at the tender stage, the Contractor should therefore carefully validate and evaluate the software requirements prior to beginning software design, and make sure that the Procurer's needs are fully understood. This will involve a dialogue between the Contractor, Purchaser and/or prime contractor, depending on the contractual arrangements. The action to take if problems with the requirements are

E.4.1 (Contd)

identified, including any consequential changes to the Software Reliability Plan and Software Reliability Case, should be agreed.

E.4.2 The methods used for requirements analysis should be appropriate for the reliability goals of the software. They include:

(a) classification of requirements;

(b) traceability analysis;

(c) requirements inspections;

(d) checklists;

(e) subjective evaluation;

(f) prototyping and animation,

E.4.3 Classification of requirements

E.4.3.1 The software requirements should be classified and organized to promote comprehension and expedite subsequent analyses. The classification should:

(a) explicitly classify the requirements according to their object, eg whether they apply to the software product, the software engineering process, human-computer interaction, or the standards to be applied;

(b) identify requirements on software product design (eg defensive programming or software architecture);

(c) identify if there are any requirements for BIT features;

(d) indicate the reliability level of each requirement;

(e) identify those requirements that are likely to change over the system's lifetime;

(f) analyse the text to identify and clarify the use of specialist notations, terms, acronyms, and non-standard usage of common vocabulary.

E.4.4 Traceability analysis

E.4.4.1 Each requirement in the software requirements, including derived requirements, should be traced to the corresponding requirement in the Procurement Specification. A

E.4.4.1 (Contd)

compliance matrix should be provided that summarizes how each requirement in the Procurement Specification and supporting documentation (eg standards) is to be implemented.

E.4.4.2 The dependencies between requirements should be analysed and documented.

E.4.4.3 The rationale for each requirement should be recorded within the limits imposed by security considerations.

E.4.5 Requirements inspections

E.4.5.1 The Contractor should carry out a formal inspection of the software requirements. This should check that the following are adequately specified:

(a) software reliability requirements;

(b) functional behaviour, distinguishing any critical functions;

(c) capacity and response time performance;

(d) configuration or architecture of the overall system as far as this affects the software;

(e) all interfaces between the software and other equipment or operators;

(f) all modes of operation of the system in which the software is required to operate, including any fail soft modes;

(g) measures to overcome failure modes of the system, hardware or software (ie fault detection and fault tolerant mechanisms) that are to be implemented in software;

(h) requirements for software self-monitoring and BIT features;

(i) areas of functionality which are likely to change;

(j) background information to enable the Software Reliability Case to summarize the system-level design approach to reliability.

E.4.5.2 General guidance on inspections is given in **F.2.3.**

E.4.6 Checklists

E.4.6.1 The Contractor should develop checklists for reviewing the completeness and correctness of the requirements. Checklists should be based on data from previous projects. One possible checklist is given below.

E.4.6.2 Interfaces

(a) Are failure modes known and their detection and handling specified?

(b) Is the software's response to out-of-range values specified for every input?

(c) Is the software's response to not receiving an expected input specified? Does the specification define the length of the time-out, when to start counting the time-out, and the latency of the time-out (ie the point past which the receipt of new inputs cannot change the output result, even if they arrive before the actual output)?

(d) Is a response specified if the input arrives when it should not?

(e) On a given input, will the software always follow the same path through the code?

(f) Is each input bounded in time? That is, does the specification include the earliest time at which the input will be accepted and the latest time at which the data will be considered valid?

(g) Are the minimum and maximum arrival rates specified for each input and communication path? Are checks performed in the software to avoid signal saturation? Is the response defined if saturation occurs?

(h) If interrupts are masked or disabled, can events be lost?

(i) Can any output be produced faster than it can be used (absorbed) by the interfacing module? Is overload behaviour specified?

(j) Are all data output to the buses from the sensors used by the software?

(k) Can input that is received before start-up, while off-line or after shutdown influence the software's start-up behaviour? Is the earliest or most recent value used?

E.4.6.3 Robustness

(a) In cases where performance degradation is required by the Procurement Specification as a means of fault handling, is the degradation predictable?

(b) Are there sufficient delays incorporated into the error-recovery responses?

(c) Are feedback loops specified, where appropriate, to compare the actual effects of outputs on the system with the predicted effects?

(d) Are all modes and modules of the specified software reachable?

E.4.6.3 (Contd)

(e) If hazard analysis has been done, does every path from a hazardous state lead to a low-risk state?

(f) Is the receipt verified of the inputs that, if not received, can lead to a hazardous state or can prevent recovery?

E.4.6.4 Data consistency

(a) Are checks for consistent data performed before control decisions are made based on that data?

(b) If diverse or redundant hardware or software is used, is a vote taken before any key decision where data may differ between channels?

(c) If diverse or redundant hardware or software is used, is a vote taken to ensure that remembered values (ie the internal state) are consistent between channels?

E.4.7 Subjective evaluation of requirements

E.4.7.1 Subjective evaluation of the software requirements is a type of internal review that may be carried out by the Contractor when preparing their proposal and as part of contract review and project risk assessment.

E.4.7.2 Subjective evaluation should be undertaken by the design team and the verification and validation (V&V) team. Each group should evaluate each requirement on a scale from 1 to 5 as defined in Table A on page E-8.

E.4.7.3 The outcome of the subjective evaluation is a profile of the understanding and perceived novelty of the requirements. If the evaluation profile is predominantly ‘1s’ and/or ‘2s’, the evaluation is satisfactory and design work maybe allowed. If the profile is predominantly ‘4s’ and/or ‘5s’, the requirements should be clarified or the team composition adjusted, and the evaluation repeated before further work is permitted.

E.4.8 Prototyping

E.4.8.1 One way of reducing specification errors is by producing a prototype of the software, early in the life-cycle, for the users to experiment with. It may be better to produce several prototypes to examine different aspects of the system (eg one prototype for basic functionality, one for user interface, etc.). Generally, prototypes will not attempt to meet all requirements of the final system.

Table A

Subjective Requirement Evaluation

(a) Designers' Evaluation

1	You understand this requirement completely, you have designed from similar requirements in the past, and you should be able to develop a design from this requirement successfully
2	There are elements of this requirement that are new to you, but they are not radically different from requirements that you have successfully designed from in the past
3	There are elements of the requirement that are very different from requirements that you have designed from in the past, but you understand it and think you can develop a good design from it
4	There are parts of the requirement that you do not understand, and you are not sure you can develop a good design
5	You do not understand this requirement at all, and you cannot develop a design for it

(b) V&V Team's Evaluation

1	You understand this requirement completely, you have tested against similar requirements in the past, and you should be able to test the software against this requirement successfully
2	There are elements of this requirement that are new to you, but they are not radically different from requirements that you have successfully tested against in the past
3	There are elements of this requirement that are very different from requirements you have tested against in the past, but you understand it and think you can test against it
4	There are parts of this requirement that you do not understand, and you are not sure that you can devise a test to address this requirement
5	You do not understand this requirement at all, and you cannot develop a test to address it

E.4.8.2 In order to be useful, prototypes have to be produced quickly, often using a different language from the final implementation. Thus a prototype is unlikely to meet all the reliability requirements for the system and should be discarded when prototyping is completed. The Contractor's discard policy should be stated in the Software Reliability Plan.

E.4.8.3 Specification animation. Specification animation is a form of prototyping carried out directly from the notation used for the specification. For example, some formal methods tools allow specifications to be directly executed. The objective of specification animation is to confirm that the specification captures the user's requirements.

As with any prototype, a specification animation will probably be deficient in areas such as response time. Any areas that cannot be explored during animation should be recorded.

The specification animation should have easily used interfaces to encourage the Purchaser's and user's representatives to explore the functionality of the specification. However, specification animations should also be tested, using formally recorded test cases and results. These tests should be designed to meet specific criteria that have been planned in advance.

A specification animation is one method of providing a diverse implementation to check the results of statistical testing (see **G.2.2).**

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Software Design and Implementation

F.1 Introduction

This annex contains guidance on the two complementary approaches to the achievement of reliability at the design and implementation phase:

(a) Fault avoidance. This requires that contractors take steps to avoid faults during software development, and to detect and correct those faults that do occur.

(b) Fault tolerance. It is unlikely that fault avoidance will succeed completely, and to achieve high reliability it is also necessary to design the software to correct or tolerate errors in service.

More information on the methods and techniques discussed in this annex can be obtained from the publications listed in Annex J.

F.2 Fault Avoidance

F.2.1 The Contractor should consider the following when developing a fault avoidance strategy:

(a) inspections;

(b) structured design;

(c) formal methods;

(d) reliability analysis;

(e) static analysis;

(f) high level programming languages;

(g) measures (metrics);

(h) testing;

(i) Cleanroom process;

(j) human factors in software design;

(k) design maturity.

F.2.2 Many of these methods provide data that can be used to assess reliability achievement and to improve the software engineering process. Data collection and analysis schemes are described in BS 5760 Part 8.

F.2.3 Inspections

F.2.3.1 Inspections should be carried out on all the intellectual products of the software development life-cycle, including specifications, designs, code, test plans and test results. The objective of such inspections is to detect errors and to ensure that the item under review conforms to higher-level specifications where applicable. They should review:

(a) the correct implementation of the component's specification, and the traceability of this to the system requirements;

(b) the apportionment of reliability allocation (see Annex B);

(c) violation of standards and codes of practice.

F.2.3.2 Inspections may be carried out by means of

(a) a desk check by an independent reviewer;

(b) a walk-through (one type of walk-through is the Fagan inspection).

F.2.3.3 It maybe helpful to use a simple checklist to guide the inspection.

F.2.4 Structured design

F.2.4.1 Structured design methods provide a methodical approach to software design by providing a set of notations and guidelines. Because they involve the production of a large number of design diagrams, tool support is essential. Examples are Structured Design (Yourdon), Jackson System Development (JSD) and MASCOT.

F.2.5 Formal methods

F.2.5.1 Formal methods are discussed in **E.3.5** in the context of specification. The Contractor may wish to consider using them for the design and implementation of critical software. The most common use of formal methods at the time of writing is to verify source code against the module specifications. This application, which is variously known as program proof, verification condition generation and discharge, semantic analysis, and compliance analysis, is supported by several tools.

F.2.6 Reliability analysis

F.2.6.1 Software failures should be considered during system-level failure modes and effects analysis (FMEA) and failure modes, effects and criticality analysis (FMECA) carried out as described in Def Stan 00-41, Section Fifteen. At the early stages of the design, the software may be considered as a single entity; as the design progresses, it may be beneficial to carry out more detailed analyses on software subsystems or modules, particularly for complex or critical software.

F.2.6.2 For complex or critical software, detailed reliability analysis maybe carried out by means of techniques such as FMEA, FMECA, software fault tree analysis or software hazard and operability studies. Analyses should be carried out by reference to a suitable description of the software, such as those described in **E.3.**

F.2.6.3 The results of software reliability analysis should be used as inputs to the system and software design processes to consider if the software failures are acceptable and, if not, devise appropriate fault avoidance or fault tolerant strategies.

F.2.7 Static analysis

F.2.7.1 Although “static analysis” can apply to any V&V technique that does not involve executing the software, the term is particularly used for tool-supported V&V that investigates the software source text for control flow and data use anomalies. The sorts of static analysis that can be carried out include:

(a) Subset analysis - identification of whether the source code complies with a defined subset (see **F.2.8.3).**

(b) Metrics analysis - evaluation of defined code measures, for example relating to the complexity of the code, often against a defined limit (see **F.2.9).**

(c) Control flow analysis - analysis of the structure of the code to reveal any unstructured constructs, in particular multiple entries into loops, black holes (sections of code from which there is no exit) or unreachable code.

(d) Data use analysis - analysis of the sequence in which variables are read from and written to, in order to detect any anomalous usage.

(e) Information flow analysis - identification of the dependencies between component inputs and outputs, in order to check that these are as defined and that there are no unexpected dependencies.

(f) Semantic analysis - the comparison of the code with a mathematical expression of the relationship between inputs and outputs. Semantic analysis can also be used to carry out

F.2.7.1 (Contd)

checks against language limits, for example array index bounds or overflow. Semantic analysis is an example at the code level of the use of formal methods (see **F.2.5).**

(g) Performance analysis - analysis of worst case conditions for any non-functional performance attributes, including timing, accuracy and capacity.

F.2.8 High level programming languages

F.2.8.1 The Contractor should use a high level language appropriate to the problem domain. In general, the fewest coding errors will occur if a strongly typed, highly structured language such as Modula-2 or Ada is used. Assembler should be restricted to the following: sections of the software where close interaction with hardware is required that cannot easily be accommodated with a high level language; situations where performance constraints cannot be met by a high level language; or very small applications where the use of a high level language, compiler and more powerful processor would increase, rather than reduce, the likelihood of faults. The Contractor should plan for additional verification and validation of assembler code.

F.2.8.2 Object oriented methods. Object oriented methods support design based on information hiding. Objects communicate by means of messages rather than by sharing data. Objects are independent, and the representation of the state and operations on the state within an object are hidden from other objects. The use of object oriented methods should improve maintainability because changes to the internal representations of a module can be made without affecting other modules. The independence of modules also facilitates reuse. However, developing an object oriented view of an essentially functional design can be difficult.

F.2.8.3 Language subsets. For critical software, the Contractor may wish to consider the use of a high integrity language subset. Such subsets remove constructs from the full language that are difficult to analyse or prone to lead to programmer error. Commercially available subsets exist for Ada and Pascal, and guidance on subsetting is available for C.

F.2.9 Measures (metrics)

F.2.9.1 Contractors should consider moving towards statistical monitoring of the software engineering process (in an analogous way to hardware manufacturing) by recording some *measures* (metrics) of the process itself and about the resulting software product. These measures are best used comparatively, for instance to compare project progress to previous, similar projects, or to identify error-prone modules within a software system. Some appropriate measures are described below.

F.2.9.2 Fault density measures. By far the most common quality measure is the number of residual faults per thousand lines of code (kloc), although this figure depends on the

F.2.9.2 (Contd)

interpretations of "line of code" and "fault", and the point in the life-cycle at which it is measured. This measure can also be applied to specification and design documents (eg specification errors per thousand words).

In general, the most useful role for fault density measures is as a general indicator of the quality of the software engineering process. However, recent research has shown that the total number of faults in the software can be used to place a conservative bound on reliability growth in service (see **G.4).**

F.2.9.3 Process measures. Process measures are measurements of the software engineering process rather than of the software itself. An example is the five maturity levels defined by the Software Engineering Institute (SEI) at Carnegie Mellon University in work sponsored by the US Department of Defense. Contractors may wish to evaluate their processes against these levels, and endeavour to move to the higher levels.

F.2.9.4 Static measures. Contractors may wish to make measurements of the size or complexity of their software. Various methods of describing software complexity are described in BS 5760 Part 8. Although many measures apply to code, a number can be used earlier in the life-cycle, for instance on specification and design documents. Many are supported by tools, although these have to be used with care. The most effective uses for static measures are:

(a) To identify problem areas. For example, modules that show an anomalously high complexity compared to the typical values for a particular software system (especially when several measures are taken together) are likely to have a relatively higher fault density and require extra scrutiny.

(b) To predict maintainability costs. Size and complexity measures, coupled with productivity data from the development life-cycle, can be used to estimate the effort needed to undertake maintenance tasks.

F.2.10 Testing

F.2.10.1 It is important to realise the limitations of testing as a method for achieving software reliability. In most software systems, there are so many combinations of inputs and internal states that it would be completely impractical to test them all. This means that at the point of acceptance into service, only a small proportion of the possible tests will have been carried out. More information on testability is contained in Def Stan 00-13.

F.2.10.2 Unit testing and module testing. This is the process of testing individual software components and modules before they are integrated into the complete system. This level of testing is usually the responsibility of individual programmers, and is poor at predicting in-service software reliability since the tests may mirror mistakes that have been made in the

F.2.10.2 (Contd)

programming. However, the results are available earlier in the development than those from the other types of test, and provide a general indication of project progress.

F.2.10.3 Structural testing. Also known as "white box" or "glass box" testing, this uses the internal structure of the program to guide the testing. It may be possible to obtain estimates of fault density and reliability from structural testing. Structural testing strategies aim to cover a certain proportion of the "objects" that make up the software (this is known as the "test effectiveness ratio" or TER): for instance, the objects might be program statements, branches, "linear code sequence and jumps" or paths. Other things being equal, the higher the proportion of these objects that are covered, the lower the number of post-delivery faults is found to be.

F.2.10.4 Functional testing. Also known as "black box" testing, this uses test data derived from the specification, and usually aims to exercise all the functions of the software. The test data is chosen to have a good likelihood of finding faults, for example by including values at the boundaries of the input domain.

F.2.10.5 Statistical testing aims to determine the reliability of the system directly by testing it in a representative environment, and is discussed further in **G.2.2.**

F.2.10.6 Exhaustive testing is in effect a type of analytical argument and is discussed in **G.5.3.**

F.2.10.7 Stress/Overload testing. Software failures frequently arise in overload conditions. When resources are limited, the software may be unable to complete an operation or it may perform too slowly to be useful in practice. Measurements on complex software systems show that failure rates can be orders of magnitude greater when resource utilisation is high. Stress/overload testing addresses such failures by concentrating on values that lead to high resource utilisation by operating the software with large values of data rate, message size, number of targets, number of users, etc.

F.2.10.8 Fault seeding. The effectiveness of testing can be estimated by deliberately introducing faults into the software, and measuring the number that are discovered by the test sets. The proportion of seeded to unseeded faults discovered can also be used to obtain a rough estimate of the original number of faults. Fault seeding is only trustworthy provided that the seeded faults are representative of real faults. Seeding can be carried out by a part of the Contractor's organisation independent from the test team, or by the Purchaser as part of contractor assessment.

F.2.11 Cleanroom Process

F.2.11.1 For critical software, the Contractor may consider adopting a very high-quality software engineering process, such as the "Cleanroom" devised by IBM's Federal Systems

F.2.11.1 (Contd)

Division. The Cleanroom is named by analogy with semiconductor fabrication units, and the emphasis is on avoiding faults rather than detecting and correcting them. Software is developed and verified using formal methods, and an independent team carries out statistical testing on the integrated software.

F.2.12 Human factors in software design

F.2.12.1 One of the most important factors in the achievement of reliable software is the quality of the development team. Attributes that should be considered include:

(a) Appropriate skill levels. The team as a whole should possess formal training and/or project experience in all the techniques and methods to be applied. If special techniques (eg formal methods) are to be employed, an expert adviser should be available.

(b) Stability. High staff turnover should be avoided, and most of the members, including the Team Leader, should have worked together on previous, successful projects.

(c) Attitude. The team should have a "total quality management" (TQM) attitude to their work, and actively seek to avoid faults. They should have high morale and good motivation.

(d) Management. The Contractor's management and organisation should be demonstrably aware of human factors issues. Team members should have a planned career progression, adequate training and comfortable working conditions.

(e) Avoidance of "groupthink". A degree of independence should be included in software assurance activities to counteract the tendency of a closely-knit team to fail to notice shortcomings in its work.

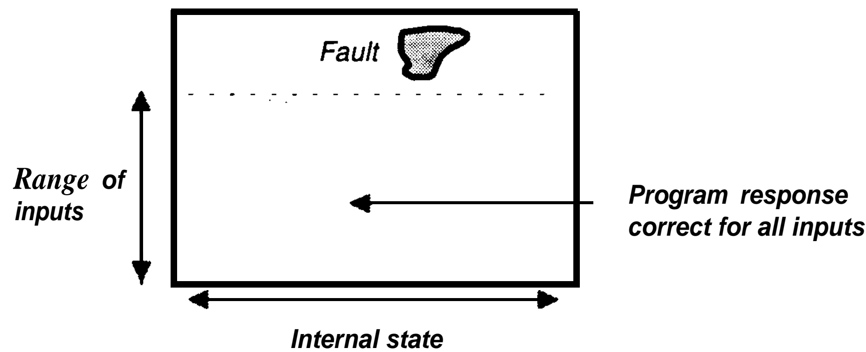
F.2.13 Design maturity

F.2.13.1 Software systems may exhibit reliability growth in the field, as reported failures lead to fault removal in subsequent releases, and software with an extensive operating history is likely to be more reliable than new software, provided changes have been well managed. In practice, the increase of reliability with design maturity is most marked in small systems, and in those systems where the emphasis is on removing faults rather than increasing functionality. The reuse of such mature software designs is a way of achieving reliability provided that the reuse is possible without change and in a similar environment. Reuse can either be of the Contractor's own software, COTS software, or other pre-existing software.

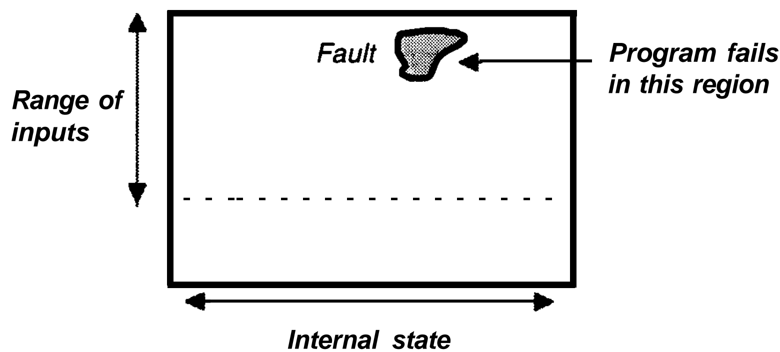
F.2.13.2 A particular problem with reuse is that it has often been observed that an item of software can be very reliable when used in one context, but fail frequently when transplanted into another application. This is primarily because the mode of use may change and the resulting differences in the input data values can "hit" a software fault and cause an error.

F.2.13.2 (Contd)

Figure 3(a) illustrates the case where the software does not fail despite a fault, because the input data does not invoke the faulty code; Figure 3(b) shows how a change in the input data causes the fault to become prominent,



(a) Failure-free Operation



(b) Failure due to Fault

Figure 3 Apparent Size of a Software Fault

F.2.13.3 Thus it is necessary to show that the past operating experience is statistically "similar" to the current application so that similar levels of reliability can be anticipated. An alternative is to reuse software that has experienced a wide range of different modes of use that should give good coverage of the most typical parts of the input space, so that at least one prior mode of use must have involved the same input values, loadings, data rates, etc., as the current application.

F.2.13.4 In principle, software reuse does not need to be at the code level; specifications and designs can also be reused, with the advantage that they can be implemented on different hardware and using different programming languages and tools. However, there is little reuse at this level in practice, and no data on its effectiveness.

F.2.13.5 Reusable components should be provided with adequate documentation, including a precise specification. Formal specifications (see **E.3.5)** will avoid many of the problems of trying to reuse ambiguously or incompletely defined software.

F.3 Fault Tolerance

F.3.1 Where high reliability is required, it is likely to be necessary to design the system to detect and mitigate software failures. This is best done by appropriate design diversity at the system level (eg a programmable and non-programmable system to implement a critical function), but where this is impractical, a degree of fault tolerance can be added to the software itself by means of defensive programming and software diversity.

F.3.2 Defensive Programming

F.3.2.1 Defensive programming is the simplest form of fault tolerance. It works by placing checks in the software that the program variables are consistent and have not been corrupted. If an inconsistency is detected, some error handling process is initiated.

F.3.2.2 Error detection. Error detection may, for example, be simply by checks included in the program that the data is within a certain range, or may involve complex relationships between data items. The code to implement these checks may be generated automatically by the compiler from assertions included in the source code (these assertions can be derived from a formal specification), but more often the checks have to be coded by hand. Some languages, such as Ada, have exception handling features that transfer control to a handler program if a check fails. Another mechanism for error detection is to associate error detecting codes (eg checksums) with the data to detect external or internal data corruption.

A serious problem with defensive programming is that the checking code adds to the complexity of the software and slows it down, and therefore it should be introduced according to a carefully-defined strategy.

F.3.2.3 Error handling. Error handling can be by backward error recovery, forward error recovery, fail soft or fail safe strategies. Error recovery is obviously preferable, but it can be hard to implement, especially if asynchronous, communicating programs are involved.

(a) Backward error recovery. This is usually implemented by making copies (known as checkpoints) of the correct state at intervals, and restoring the state from the latest checkpoint if an error is detected. It is most useful against transient hardware failures and external faults.

(b) Forward error recovery. This uses redundant information to repair corrupted data. Error detecting codes are often implemented with extra bits to enable error recovery. Database and file systems commonly use redundant pointers for error recovery. Diversity can also be used (see below).

F.3.2.3 (Contd)

(c) Fail soft. Here the design philosophy is not to mask failures but to reduce the performance of the system in a defined way. A fail soft philosophy may, for example, be implemented by reducing the functionality, assuming that some partial operational capability can be identified, or by discarding data (eg alternate inputs).

(d) Fail safe. It maybe possible to handle errors by halting in a safe way. Examples of fail safety are seen in railway signalling, where all signals are set to danger if an error is detected in the interlocking system, and in nuclear power generation, where the reactor is shut down if the safe operating parameters are exceeded. Fail safety is not possible at the system level if high availability is required, but maybe possible at the subsystem level if it can be arranged for a faulty component to "fail silent" (ie cease producing output) and a backup subsystem to detect this and take over.

F.3.3 Software Diversity

F.3.3.1 Software diversity is a form of fault tolerance based on the use of two or more diverse programs to carry out critical functions, on the assumption that the same fault is unlikely to occur in all the versions. In its most elaborate form, diversity may involve three or four versions of the software, written by independent teams using different design methods and programming languages, and running on different processors.

F.3.3.2 Diversity enables failures of individual versions to be detected, and fault tolerance to be implemented, by using the output agreed on by the majority to control the system. If all the versions disagree, the system should fail soft or fail safe if possible.

F.3.3.3 Diversity is vulnerable to common mode faults affecting several of the versions, which limit the reliability gain and make it hard to predict. Research has shown that diverse implementations may suffer from common design errors, possibly because certain parts of the design are intrinsically difficult. It may also be difficult to maintain data consistency between the versions, especially if the software maintains an internal state.

F.3.3.4 Software diversity may be difficult to implement for both technical and managerial reasons. Shared activities make it very hard to maintain isolation between the teams, and it has been found that the costs of diversity increase rapidly with the number of versions. It is likely to be more cost-effective to concentrate resources on fault avoidance and detection during development, and diversity, if it is used, should be employed at a system, rather than software, level.

F.3.4 Verification of Fault Tolerance

F.3.4.1 Verification of the effectiveness of fault tolerance is very difficult and involves different techniques from normal software testing. System-level fault tolerance is normally verified by simulating failures of components and fault injection on the system or interfaces.

F.3.4.1 (Contd)

Software-level fault tolerance (eg defensive programming) is verified by seeding software faults.

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Evaluation of Software Reliability

G.1 Introduction

G.1.1 This annex describes the methods that can be adopted to evaluate the software reliability that has actually been achieved by application of the Software Reliability Plan. It discusses evidence from testing, field data, fault data and analytical arguments. More information on the methods and techniques discussed in this annex can be obtained from the publications listed in Annex J.

G.1.2 Where possible, the Contractor should carry out software reliability evaluation as part of normal system reliability tests and trials, to minimize costs and to exercise the software in the system environment.

G.2 Evidence from Testing

G.2.1 Reliability growth modelling

G.2.1.1 This technique attempts to predict in-service reliability from data on the times between failures as the software is tested and design faults removed towards the end of the development phase. It can be used to assess the effectiveness of the software engineering process, and to predict when the software will meet its reliability requirements. Various software reliability growth models have been developed and there is software available to perform the extensive calculations that are required. See BS 5760 Part 8 for further details.

G.2.1.2 While reliability growth modelling makes it possible in principle to obtain measures of the operational reliability of a program, there are several difficulties with using the approach on software with stringent reliability requirements. Most importantly, there is a strong law of diminishing returns operating when software is debugged by waiting for faults to be revealed during testing.

G.2.1.3 Reliability growth modelling is based on testing during development. The expectation is that the software will meet its reliability requirements in service, but sometimes the exposure of many copies of the software to operational conditions will reveal additional failures. Further reliability growth can occur if arrangements have been made so that design faults that lead to in-service failures are diagnosed and corrected (see also **F.2.13).**

G.2.2 Statistical testing

G.2.2.1 The demonstration of achieved software reliability through tests and trials should be a key part of the software reliability programme. The aim should be to subject the software to test data that is statistically similar to the in-service environment. Tests can either be carried out with the software installed in the system, or by means of a simulator. See **J.9(c)** for information on developing operational profiles.

G.2.2.2 System reliability growth testing, as discussed in Def Stan 00-41, Section Twenty-Six, will provide reliability data under operational conditions.

G.2.2.3 The tests should be carried out over a period several times the required mean time to failure. It may be difficult to attain this with software with very stringent reliability requirements. Some ways in which testing can be speeded up are:

(a) Testing many copies of the software in parallel with different data sets.

(b) Testing on a faster computer than the eventual target, although this will not uncover errors in the target processor, or in the compiler unless both test and target processor use the same object code.

(c) Using goal-directed ("trajectory") testing. For a system that is only required to operate occasionally, such as a shut-down system, the test data can concentrate on values that should initiate action. Because of memory effects, a period of working prior to the demand should be included.

G.2.2.4 Because of the large numbers of tests involved, it is desirable to use a diverse implementation of the software to check the results. This is known as "back-to-back" testing. Prototype versions or a specification animation (see **E.4.8)** can be used as the diverse implementation. Alternatively, the tests can be checked against a real-world simulator to establish that failures do not occur.

G.2.2.5 Very high reliability software may not fail at all during statistical testing. If a particular version of the software has not failed on test, and if the testing has been carried out for a time t, it can be shown that there is a 50:50 chance that the software will run for another time *t* without failing. See **J.9(a)** for details of this result, and **J.9(b)** for information on stopping rules for testing.

G.2.3 Performance testing

G.2.3.1 Testing maybe carried out to establish that the non-functional performance requirements have been met. Such tests should include:

(a) tests of specific design features for reliability (eg overload handling and interface error handling);

(b) overload/stress tests (see **F.2.10.7);**

(c) fault tolerance tests, including tests of fault detection, recovery and isolation mechanisms (see **F.3.4);**

(d) normal and worst case resource utilisation measurements;

G.2.3.1 (Contd)

(e) real-time performance tests (eg time response and throughput).

G.3 Use of Field Data

G.3.1 The use of previous operational history of software that is to be reused may provide a means of evaluating software reliability. Caution is needed, however, since manual reporting schemes suffer from under-reporting and misdiagnosis, especially if the failure is transient or the system is repaired in the field. More accurate failure data may be obtainable through the use of BIT (see Def Stan 00-13).

G.3.2 The use of operational history is a valid approach provided that the particular software product has been used in a range of different applications that give good coverage of the most typical parts of the input space. This approach has to be complemented by good configuration and quality management systems at the developer's so that users' problems are recorded. Unfortunately very few commercial software suppliers will provide failure data to potential users.

G.4 Evidence from Fault Data

G.4.1 Recent research has developed a theory for software reliability growth that allows a conservative bound to be placed on the mean time to failure (MTTF) of software after a period of use on the basis of the initial number of faults. The theory is based on the assumption that a stable operational environment will result in a fixed but unknown failure rate for each defect. The theory shows that the software reliability after a usage time T is bounded by:

$$\mathrm{MTTF} \geq eT/N$$ (e times T divided by N)

where N is the initial number of faults and e is the exponential constant (2.718.. .).

G.4.2 The theory assumes that all failures are perfectly diagnosed and the underlying faults are corrected, but the predictions are relatively insensitive to assumption violations over the longer term. Less conservative results can be obtained if additional assumptions are made about the failure rate distribution of faults. See **J.9(d)** for further details.

G.5 Analytical Arguments

G.5.1 Analytical arguments are essentially arguments that certain faults are *logically impossible.* In some circumstances, it may be easier to show by analysis that an event is logically impossible than to show by testing that it is very unlikely (eg has a probability of failure of 10^{-9} per hour). There is always a small doubt in analytical arguments because of assumptions about the environment, the soundness of the methods used to construct the arguments, etc.

G.5.2 Examples of analytical arguments are:

(a) analysis to show that the response time, throughput, capacity and resource usage areas specified. Note that tools may be available to assist this process;

(b) analysis of the effectiveness of fault detection (including BIT), fault tolerance and fail safety features, including analysis that the overheads from these features are within the specification;

(c) the use of formal methods to show that certain properties are logically bound to hold of the software (examples of this might be that critical functions occur correctly, or that undesirable behaviour cannot occur);

(d) the use of static analysis to show that coding errors have not occurred;

(e) reverse compilation of object code to show that compiler errors have not occurred;

(f) model checking to show that real-time failures (eg deadlock) cannot occur;

(g) analysis to show that all stimuli have a valid response.

G.5.3 Exhaustive Testing. For certain small, simple systems, it may be possible to test all combinations of inputs and internal states. Exhaustive testing needs to be carried out with special care for software since changes in the internal state over time may cause subtle errors (for example, the memory may overflow after a large number of cycles if reinitialisation is not properly performed). Exhaustive testing is in effect a form of analytical argument because it provides assurance that the software is logically correct with respect to its specification, and has the advantage of including the compiler, link-loader and, if carried out on the target system, the processor in the testing. However, it will not be practicable for the great majority of systems.

H.1 ASICs

H.1.1 Introduction

ASICs are being increasingly used in modern electronic systems. These circuits blur the conventional distinction between hardware and software. A functional design in a high level hardware description language (HDL) is transformed by what is often termed a “silicon compiler” into a set of photo-lithographic masks for integrated circuit production. State-of-the-art ASICs may contain up to a million gates.

H.1.2 This annex describes the techniques that can be applied for the assurance of reliability for ASICs

H.2 Reliability Achievement for ASICs

H.2.1 Essentially ASICs are another, if rather unusual, form of software with the same potential for containing design faults, and should be subjected to similar forms of evaluation. Assurance is required that the design is logically correct with respect to its specification.

H.2.2 Commercial tools to enable model checking and verification of HDL designs are available. For high reliability requirements, formal methods should be used (see **E.3.5).** In addition, design simulation should be used to check the validity of the design. Exhaustive simulation can be achieved even for large input spaces by partitioning the circuit into a series of sub-modules. This requires partitioning to be an essential part of the functional design and is an overhead appropriate to critical applications.

ASICs are also hardware, so assurance is additionally required of the integrity of the translation of the design into silicon. This will involve assurance that the following are satisfactory:

(a) the fabrication technology, which changes rapidly;

(b) the acceptance test procedures for the fabricated chip samples, which will change as the fabrication technology changes;

(c) the tests to be applied when reproducing the design on a production basis;

(d) the built-in tests to detect production and operational faults.

H.2.4 BIT for ASICs utilizes test vector generation and fault detection by an added part of the circuitry. This concept can be used for production tests and for automatic on-line diagnostics to detect operational faults, which may greatly extend maintenance test intervals. The fact that the design is “frozen” in silicon also has potential benefits in simplifying version and configuration control and could be seen as the best form for a certified device or system.

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