
British Standard

Reliability of constructed or manufactured products, systems, equipments and components

Part 1. Guide to reliability and maintainability programme management

Fiabilité des produits, systèmes, matériels et éléments manufacturés

Partie 1. Guide pour la gestion des programmes de fiabilité et de maintenabilité

Zuverlässigkeit von zusammengesetzten oder angefertigten Erzeugnissen,

Systemen, Ausrüstungsteilen und Bauteilen

Teil 1. Leitfaden für das Management von Zuverlässigkeits- und Wartungsprogrammen

Foreword

This Part of BS 5760, having been prepared under the direction of the Quality, Management and Statistics Standards Committee, supersedes BS 5760 : Part 1 : 1979, which is withdrawn.

Although only five Parts of this standard have been prepared at present, further Parts are envisaged in order to give greater emphasis to certain aspects of reliability and to take account of new developments. The first five Parts may be summarized as follows.

**Part 0. Introductory guide to reliability.* This Part is aimed at directors of companies looking for overall advantages, engineers not trained in quality and reliability to show how reliability can help in their technical decision making, and at middle management not specialized in engineering to demonstrate how reliability should be dovetailed in with other disciplines to give them the best result.

Part 1. Guide to reliability and maintainability programme management. This Part discusses the essential features of a comprehensive reliability and maintainability programme for the planning, organization, direction and control of resources to produce systems, equipments and components which will be reliable and maintainable. This guide is concerned mainly with what has to be done, and why, when and how it has to be done, but it cannot be specific about who should do it and where, because organizations and projects vary widely. Recommendations are given for the drafting of specifications for reliability and maintainability achievement.

The main considerations for the assessment of reliability are reviewed and this is followed by details of the means

by which reliability data are transmitted from the point of collection and recording to the point of storage and/or usage.

Part 2. Guide to the assessment of reliability. This Part recommends general procedures for the assessment of reliability and contains guidance, for the reliability practitioner, on the quantitative and statistical aspects of reliability, such as reliability modelling, the provision of data, and the concepts of redundancy and simulation.

Part 3. Guide to reliability practices: examples. This Part contains authentic practical examples illustrating the principles established in BS 5760 : Parts 1 and 2.

**Part 4. Guide to specification clauses relating to the achievement and development of reliability in new and existing items.* This Part provides guidance on the form and content of clauses concerned with the achievement of the reliability of products in the various types of specifications that cover the definition, use and maintenance of manufactured and constructed products. Information is also given on specifications related to the management of reliability programmes.

NOTE. This British Standard makes numerous cross-references to BS 4778 'Glossary of terms used in quality assurance (including reliability and maintainability terms)'. The glossary contains definitions relating to reliability concepts applicable to the guide and it is essential that these definitions and concepts be fully understood if this guide is to be interpreted correctly. For this reason it is recommended that BS 4778 be read in conjunction with BS 5760.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

* In preparation.

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Section one. General

0 Introduction

A standardized systematic approach to reliability is essential to ensure that statements are consistent and unambiguous in all communications concerning reliability. As well as providing a basis for the preparation of reliability programmes, this standard can be used in preparing documents concerned with the specification of reliability or the reporting of reliability data or tests.

It is vital that reliability be considered in a manner similar to a characteristic of a system, equipment or item from its design conception to the end of its working life, and that the reliability experience of one generation of products, engineers or technology is used by the next. This requires that each factor affecting reliability at any stage in the life of an item be identified and considered in its relationship to the other factors. This procedure can be formalized into a reliability programme. It may be necessary to divide such a programme into two parts, one of which may be the concern of the designer and manufacturer, and the other the concern of the user. It is most important that consideration be given to the reliability of items or parts which are used by one manufacturer but produced by another, i.e. subcontractor evaluation and vendor appraisal (see BS 5750).

Satisfactory reliability has traditionally been achieved by the use of codes of practice or methods of working that have been shown by experience to give good results for established products. However, with the increase in pace of change and performance expectations it is no longer sufficient to consider reliability in purely qualitative terms when its achievement often demands the specification of quantitative acceptance/rejection criteria also. Accordingly the onus should be on all parties (i.e. the designer, supplier, purchaser or any other responsible authority) to specify quantitative requirements wherever possible.

With the need to satisfy competing constraints, including stricter health and safety requirements, the advent of new materials, pressure to reduce costs, reliability should be expressed in quantitative terms if it is to be given its proper weight. For example, an item or product may be required to achieve at least a certain useful life, not to exceed a certain failure rate or to have an extremely high availability. Quantitative statements relating to reliability should then be made which may be accompanied by stipulations that certain codes of practice be followed.

One aspect of quantitative reliability that requires emphasizing is that often reliability can be predicted even for items or projects of new design and high cost, such as a ship's propulsion system or a new kind of nuclear reactor pressure vessel, but only if there is sufficient knowledge of the processes leading to failure, including data based on the statistical analysis of observations made.

The designer's or user's confidence that his reliability requirements will be met depends on:

- (a) the adequacy of the data about failures;
- (b) the correct interpretation of those data in the existing environment;
- (c) a disciplined approach to the specification and design of the product or service.

Data should be obtained about failures from:

- (1) reliability testing;
- (2) field data;
- (3) knowledge of the physical processes leading to failure.

A reliability and maintainability programme sets out to provide products with acceptable levels of reliability and maintainability at an acceptable cost rather than products with improved reliability and maintainability regardless of cost. For this reason the quantitative approach is essential. The qualitative approach is effective in improving reliability and maintainability but the improvement cannot be measured and quantified.

In general terms and philosophy this standard is equally applicable to all parts of a system, including the software.

However, it is important to recognize that software as a product is different from all other engineering products in that it is not tangible, and it does not wear out. Software exhibits faults, but unlike hardware faults they originate in undetected mistakes in the design logic. These mistakes generate faults only when that part of the program is executed and specific (input) conditions exist. The mistakes mature into failures when they affect the response of the system. Such software induced system failures exhibit time dependency because the range of system inputs may vary with time and the process of a mistake maturing into a failure is of uncertain duration and depends on the application of the system. Software reliability assurance is therefore not a question of showing, avoiding or compensating for changes such as wear, but of attempting to detect or limit the effect of mistakes in design.

While systems have always had a logic content, the advent of computers has afforded the opportunity to incorporate very large, complicated and often subtle logic structures. The structures often exceed the capability of the human mind to perceive them in total and thus the difference in scale of the logic now possible brings a greater chance of human error at all stages of the life cycle.

The terms and expressions used in this standard relate to hardware and software except where stated otherwise. It should be borne in mind that for software all potential failures are equally present in all samples of the product and are only awaiting the appropriate set of input conditions to trigger them off.

1 Scope

This Part of BS 5760 provides guidance on reliability and maintainability programme management. It discusses the essential features of a comprehensive reliability and maintainability programme for the planning, organization, direction and control of resources to produce systems, equipments and components which will be reliable and maintainable. In management terms it is concerned with what has to be done, and why, and when and how it has to be done, but it cannot be specific about who should do it and where, because organizations and projects vary widely.

NOTE 1. The possible allocation of activities to the various parts of an organization (management, technical, production, marketing, purchasing and finance) is given in BS 5760 : Part 0*.

Section two reviews the essential features of a comprehensive reliability programme setting out a logical framework in which the activities described in the other sections can take place.

Section three describes the steps that should be followed when a specification of reliability is drafted. The section provides guidance on the inclusion of reliability clauses in specifications relating to the performance, construction, testing and installation of manufactured products, and indicates the nature of the reliability statement appropriate to each specification.

Section four is an introduction to the means by which quantitative values can be assigned to the reliability of systems, equipments and components at various stages in their life cycle, and the factors that influence that assessment.

NOTE 2. The methods described in section four are developed in greater detail in BS 5760 : Part 2.

Reliability models for the software elements of systems are being developed, but their acceptability is still under debate. BS 5760 : Part 2 : 1981 was written for systems not containing software, and the methods outlined are, therefore, not necessarily applicable to the software elements of systems.

Section five describes the processes of assimilation and utilization of the data on which assessment and prediction of reliability are based.

NOTE 3. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 5760 the definitions given in BS 4778 apply together with the following.

2.1 part. Things that are put together to form an item and includes hardware and/or software.

2.2 software. Computer programs, procedures, rules, and all associated documentation concerned therewith.

NOTE. 'Computer' includes microprocessors and other stored program logic control devices.

2.3 maintenance. The combinations of all technical and corresponding administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function.

NOTE. In hardware this usually means restoring an item to its original condition, but in software it always means changing the item from its original condition (to correct mistakes).

2.4 production phase (for systems containing software). The replication of software to many users and/or the configuration of specific systems from existing software, the actual software preparation being considered as part of the 'development phase'.

2.5 mistake (error). A human action that produces an unintended result.

2.6 fault. An accidental condition that causes a functional unit to fail to perform its required function.

2.7 failure. The termination of the ability of a functional unit to perform its required function.

2.8 handling, storage and transportation specification. The document that describes the procedures for packing and transportation to ensure that the conditions encountered by the equipment do not exceed those for which it is rated.

2.9 proof test. The application of a specified load or stress to an item, to see if anything unexpected happens, including a task to check that the documentation agrees with the item being examined.

* In preparation.

Section two. Reliability and maintainability programme

3 Introduction to section two

3.1 Aims of a reliability and maintainability programme

The aims of a reliability programme are to ensure that adequate and effective effort is brought to bear on reliability as a principal quality measure during all phases of the life-cycle of an item (from definition through design and acceptance into service, to the end of its working life) and that the activities which contribute to reliability are properly integrated with other contract/specification activities. A reliability programme should provide continuous study of both quantitative and qualitative requirements throughout all phases of a project; reliability assessments should be updated; specified requirements should be verified; and the reliability activities should be integrated with other elements of the development, production and operation programme.

In many cases, and particularly with large complex installations, the reliability of systems is dependent on the

maintainability of the sub-systems. Where availability is an important quality, a maintainability programme should be conducted.

In many projects there are no sharp demarcations between the definition, design and development, production and operation phases. However, for clarity, distinctions are drawn in this section. The activities appropriate to the different phases are given in table 1.

The activities are also shown in flow diagram form in figure 1. They are explained in the text of this section in relation to the overall project management responsibilities and time scale. Some of these activities have a direct bearing on the reliability achieved in service but they are contained in other programme elements. The reliability programme should therefore be prepared and read in conjunction with the other parts of the quality programme and with the maintainability and safety programme.

NOTE. See BS 4891 for guidance on quality programmes and BS 5750 for guidance on quality systems specifications.

Table 1. Programme activities during the principal phases of a project (see clause 4)

Phase	Activities	Subclause
Definition	Reliability feasibility study Statement of reliability objectives and requirements Reliability specification and contract formulation	4.1.1 4.1.1 4.1.2
Design and development (including initial manufacture)	Analysis of parts, materials and processes Analysis of established and novel features Failure mode, effect and criticality analysis Incident sequence analysis (fault tree analysis) Stress and worst case analysis Redundancy analysis Human factors Design change control Design review Design audit Safety programme Maintainability programme Parts and sub-assembly testing Performance testing Environmental testing Accelerated testing Endurance testing Reliability growth testing Reliability demonstration Data collection, analysis and feedback	4.2.1.2 4.2.1.3 4.2.1.4 4.2.1.5 4.2.1.6 4.2.1.7 4.2.1.8 4.2.1.9 4.2.1.10 4.2.1.11 4.2.2.1 4.2.2.2 4.2.3.2 4.2.3.3 4.2.3.3 4.2.3.4 4.2.3.5 4.2.3.6 4.2.3.7 4.2.3.8
Production	Preservation of reliability achievement Quality conformance verification Screening (run-in, bed-in or burn-in) of components and assemblies Reliability demonstration Additional software check	4.3.1 4.3.2 4.3.3 4.3.4 4.3.5
Installation and commissioning	System acceptance testing Commissioning tests Quality assurance Reliability growth Reliability and maintainability demonstration Data collection Reliability and maintainability assessment	4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.4.6 4.4.7
Function and maintenance	Data collection, analysis and feedback Redesign/modification Maintenance	4.5.1 4.5.1 4.5.2

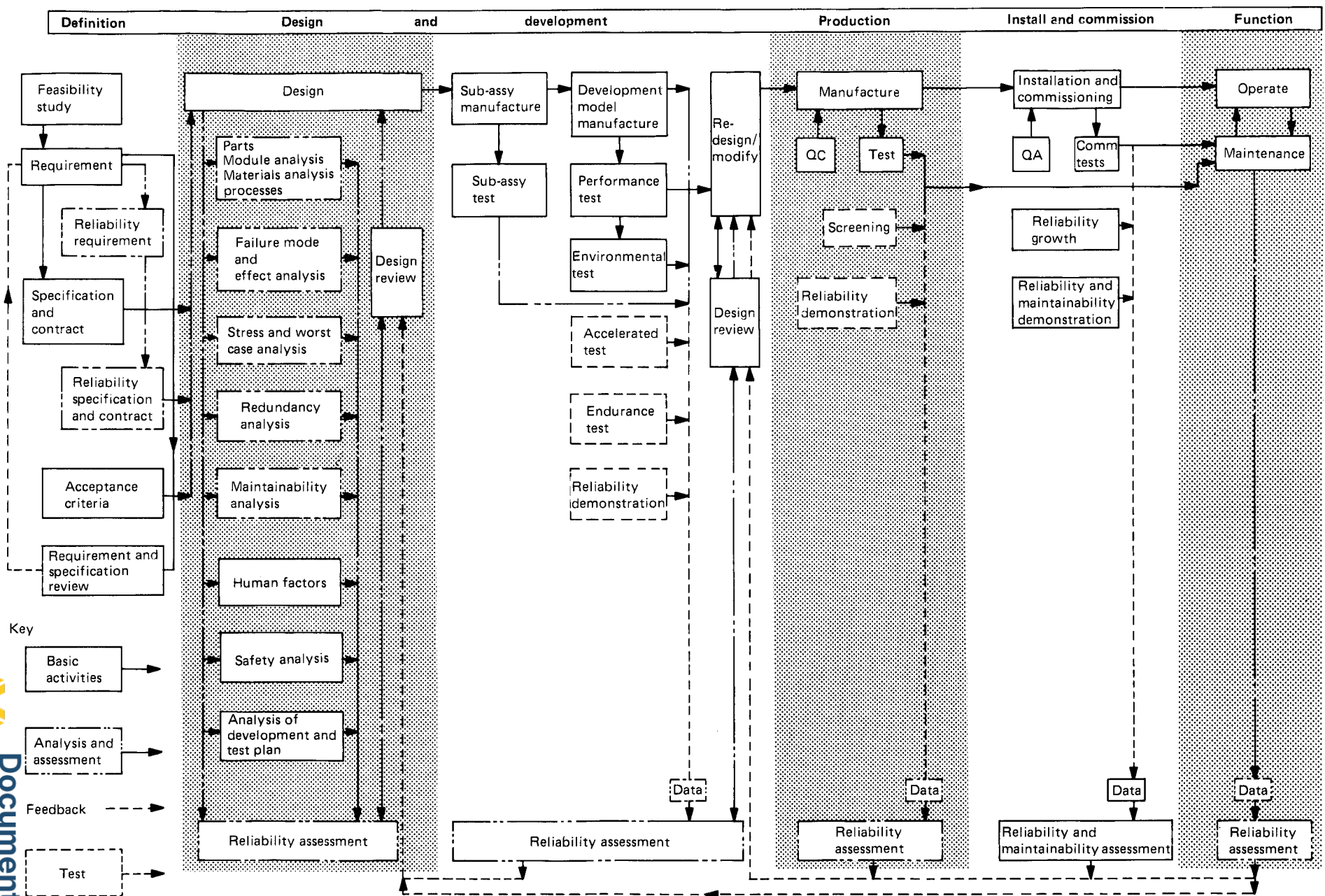


Figure 1. Reliability and maintainability programme concept

3.2 Cost considerations

It may be neither necessary nor desirable to implement in full all the activities described in this section. A suitable compromise should be reached whereby reliability needs are balanced against all the other factors. Whole life costs are the sum of the initial acquisition costs and costs of subsequent ownership. For complex equipments the ownership cost can be a high proportion of whole life costs. Furthermore, a properly integrated reliability programme (see figure 2) can show an overall cost benefit to the manufacturer in terms of reduced costs of technical support, repair and replacement, and warranties. It can also lead to increased competitiveness and goodwill and have a vital significance in the prevention of any product liability claims. It follows, therefore, that there should be continuous communication between the design authority/manufacturer and the customer/user after the customer has formulated his reliability requirements. The procedures set out in this section give guidance on implementing an effective reliability programme, which should be integrated with design, development and production activities, thus allowing its overall objectives to be achieved in the most cost-effective way.

NOTE. For further guidance, see BS 6143.

3.3 Other considerations

The success of a reliability programme depends on carrying out the activities given in table 1 and monitoring them. It may be necessary to adjust the programme to suit the particular phase of the project and to take account of such aspects as:

- (a) the complexity of the item, the development risk and the function of the product and the hostility of the environment in which the product is to be used;
- (b) the quantity ordered or in production/construction;

- (c) the resources available (including time and finance);
- (d) the value of the appropriate reliability characteristic for the principal phases in the total life;
- (e) demonstration and guarantees required.

3.4 Relative effectiveness of programme activities

It is not possible to predict accurately the relative effectiveness of each activity on improving reliability. The choice of activities and the resources to be expended on each should be based on past experience of similar projects. The following recommendations are offered as a general guide.

- (a) The earlier a design change can be agreed, the lower the total cost is likely to be. The cost of making a design change at the production or use stage is usually many times the cost of doing so at the initial design and development stages.
- (b) For complex items, design evaluation and review, use of proven parts and processes, and the use of redundancy or derating within the design can greatly enhance overall system reliability. Large scale use of system redundancy can greatly improve overall system reliability, but at an increase in initial cost and maintenance load. It should be noted that the useful system redundancy may be limited by common mode (or common cause) failures.
- (c) Reliability testing, including corrective action, carried out during the development and production phases, is an effective means of increasing the reliability of complex items as well as increasing confidence that the required level has been attained.
- (d) Reliability improvement depends on several factors, such as the effectiveness of procedures for identifying, reporting and taking action on failures, the way the programme is managed and the use to which failure analyses are put.

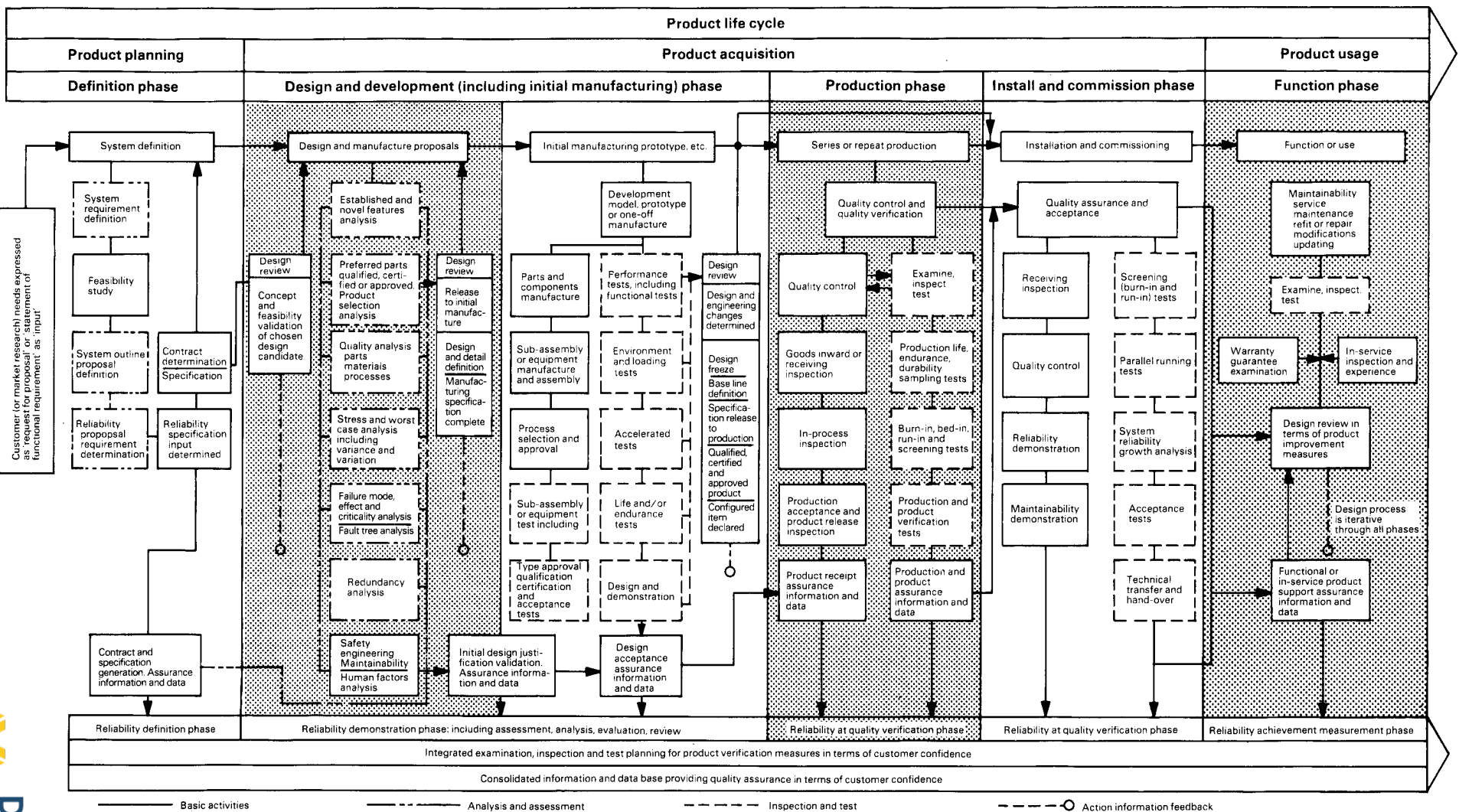


Figure 2. Typical reliability and maintainability programme

4 Programme activities

4.1 Definition phase

4.1.1 Reliability feasibility study and statement of objectives and requirements. At the definition phase, the originator of the requirement should consider the reliability characteristic that will be required of the item in its different phases, and the factors that will influence this.

These factors include:

- (a) the complexity of the item;
- (b) the state of development of similar items and of the parts to be used;
- (c) the method of use of the item, such as duty cycles, maintenance and expected life;
- (d) the environmental conditions expected: these should cover operating and non-operating conditions, packaging, transport and storage;
- (e) the constraints imposed by other requirements, e.g. performance, size, mass, safety and costs;
- (f) provision for changes in requirements during the life of the system.

For complex items it may be necessary to carry out initially a preliminary study to assess the reliability likely to be attainable under the conditions expected in order to set a sensible target. This study should be in accordance with section four.

4.1.2 Specification and contract. When the feasibility of each relevant reliability characteristic has been determined and its value set and agreed, it should be stated as the specified reliability for the item that is to be achieved and demonstrated. This requirement or objective should then be included in a specification or contract. The specification should take into account factors such as those given in 4.1.1 in as much detail as is necessary, and it should be drawn up in accordance with section three. Arrangements should be made in the overall programme to allow for the reliability elements to be reviewed in terms of the overall programme at predetermined intervals.

4.2 Design and development phase

4.2.1 Analyses and other activities

4.2.1.1 General. Subclauses 4.2.1.2 to 4.2.1.11 describe those activities which, during the design and development (including initial manufacturing) stages, can be carried out by the supplier or by an independent assessor, or as may be required by the purchaser. Because of the complexity of some systems, the level at which the following analyses are carried out should be carefully selected, taking into account costs, complexity of analysis and potential benefits.

4.2.1.2 Parts, materials and processes analysis. The design stage should include an analysis of the reliability implications of all parts, materials and processes called up in the initial design. As far as practicable, parts or sub-assemblies whose reliability characteristics (at the stress levels expected) are known, should be selected. Wherever possible, the number of different part types should be minimized by use of standard products.

For systems containing software, the designer should select (based on known reliability data) existing software, proved languages and compilers, etc.

4.2.1.3 Established and novel features analysis. The design should be analysed to identify those features that are established practice and those that are novel, including features that use novel components, novel software techniques, etc. or use established components in novel ways. The reliability of each innovation in the design should be assessed by analysis and/or testing in order to justify objectively the proposed innovation.

4.2.1.4 Failure mode, effect and criticality analysis (FMECA). The design should be analysed in order to determine possible modes of failure and their effects on system operation. The primary objective of such analysis is to discover critical failure areas and design features. It can be carried out either by starting at the system level and expanding downwards, or from the component level upwards, to a level commensurate with necessity, time available and required assurance. Within the analysis, each potential failure should be considered in the light of the probability of occurrence and categorized as to its probable effect on the successful operation of the system or item. This will aid in allocating resources for corrective design action, reliability and development engineering. Such analysis should be a major consideration in design reviews and should always be used to provide acceptance criteria for test planning and, when required, the establishment of check out and diagnosis procedures. Depending upon the nature of the system, major sub-units may require separate analysis, often to meet specific legal or safety code requirements, e.g. ships, bridges, aircraft, high pressure vessels in process plants and real time computing systems.

Elements of the analysis are:

(a) *failure mode analysis*: a study of the system and the working interrelationships of its components under various anticipated conditions of operation (normal and abnormal) in order to determine probable failure location, mode and mechanism by which failure will occur;

(b) *failure effect analysis*: a study of the potential failures that might occur in any section of the system in order to determine the probable effect of each on all other components, other sections, and on probable operational success;

(c) *failure criticality analysis*: a study of the potential failures in any section of the system in relationship to other sections of the system, in order to determine the severity of each failure effect in terms of a probable safety hazard, unacceptable degradation of performance, or loss of operation or availability of the system.

4.2.1.5 Incident sequence analysis (fault tree analysis). In cases where a major system failure can be identified from the beginning it may be helpful to use a fault tree analysis to identify possible causes. This consists of an analysis of possible causes starting at system level and working down through system, sub-system, equipment and component, identifying all possible causes.

NOTE. This technique is often used for the development of maintainability programmes and maintenance procedures.