BRITISH STANDARD

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IEC 1014:1989

Reliability of systems, equipment and components —

Part 6: Guide to programmes for reliability growth

Committees responsible for this British Standard

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Association for Consumer Research (ACRE)
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British Gas plc
British Railways Board
British Telecommunications plc
Cable and Wireless plc
Civil Aviation Authority
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Contents

National foreword

This Part of BS 5760 has been prepared under the direction of the Quality, Management and Statistics Standards Policy Committee. It is identical with IEC 1014:1989, "*Programmes for reliability growth*", published by the International Electrotechnical Commission (IEC).

Seven Parts of this standard have now been published and these may be summarized as follows.

— *Part 0: Introductory guide to reliability.* This Part provides guidance to directors of companies who need to know why reliability is important to them, to engineers not trained in quality and reliability to show how reliability should influence their technical decision making, and to middle management not specialized in engineering, to explain how measures to achieve reliability should be integrated with other aspects of project management to give optimum results.

— *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, equipment and components which will be reliable and maintainable. It includes consideration of the specification and assessment of reliability and maintainability and of arrangements for the collection of reliability data.

— *Part 2: Guide to the assessment of reliability.* This Part recommends general procedures for the assessment of reliability of hardware systems 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 Parts 1 and 2 of BS 5760.

— *Part 4: Guide to specification clauses relating to the achievement and development of reliability in new and existing items.* This Part provides more detailed guidance on the specification of reliability.

— *Part 5: Guide to failure modes, effects and criticality analysis (FMEA and FMECA).* This Part describes failure modes and effects analysis (FMEA) and failure modes, effects and criticality analysis (FMECA), and gives guidance on the application of these techniques.

— *Part 6: Guide to programmes for reliability growth.* This Part describes procedures to expose and remove weaknesses in hardware and software items in order to achieve acceptable reliability in a product. It explains basic concepts, management and test procedures and describes techniques for analysis and correction of failures.

Further Parts are envisaged in order to provide guidance on other techniques of reliability management. At present three further Parts are in the process of being drafted, and these are as follows.

— *Part 7: Guide to fault tree analysis.*

— [1]*Part 8: Guide to the assessment of reliability of systems containing software.* This Part will provide guidance on the assessment of reliability of systems containing software.

— *Part 9: Guide to reliability block diagrams.*

[1] Currently published as a Draft for Development, DD 198:1991.

Cross-references

International standard	Corresponding British Standard
IEC 50(191):1990	BS 4778 Quality vocabulary Section 3.2:1991 Glossary of international terms (Identical)
IEC 300:1984	BS 5760 Reliability of constructed or manufactured products, systems, equipments and components Part 1:1985 Guide to reliability and maintainablility programme management (Technically equivalent)

The Technical Committee has reviewed the provisions of IEC 605-1:1978, IEC 605-2 (draft approved for publication), IEC 605-3 and IEC 605-4:1986, to which reference is made in the text and has decided that they are suitable for use in conjunction with this standard.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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Introduction

Reliability improvement by a growth programme should be part of an overall reliability activity in the development of a product. This is especially true for a design which uses novel or unproven techniques or component parts or a substantial content of software. In such a case the programme may expose, over a period of time, many types of weaknesses having design-related causes. It is essential to reduce the probability of failure due to these weaknesses to the greatest extent possible to prevent their later appearance in formal tests or in the field. At that late stage, design correction is often highly inconvenient, costly and time consuming.

Life cycle costs will be minimised if the necessary design changes are made at the earliest possible stage.

IEC 605-1, Clause **1**, refers to a "reliability growth (or improvement) programme" employing equipment reliability testing, with the principal object of upgrading the reliability. The testing and environmental arrangements for such a programme are essentially the same as those covered by IEC 605-1, IEC 605-2 and IEC 605-3.

1 Scope

This international standard specifies requirements and gives guidelines for the exposure and removal of weaknesses in hardware and software items for the purpose of reliability growth. It applies when the specification calls for a reliability growth programme of equipment (electronic, electromechanical and mechanical hardware as well as software) or when it is known that the design is immature and is unlikely to meet the requirements of a compliance test without improvement. A statement of the basic concepts is followed by descriptions of the management, planning, testing (laboratory or field), failure analysis and corrective techniques required. Mathematical modelling, to estimate the level of reliability achieved, is outlined briefly.

2 Object

This standard focuses principally upon reliability improvement through testing but the same general principles may also apply to other activities, even if not required by a formal programme.

Improvement may be based on the results of:

— theoretical studies (e.g. failure modes and effects analysis);

— field trials;

— users' experience;

— tasks not aimed primarily at reliability improvement.

3 Terms and definitions

General reliability terms used in this standard comply with Chapter 191 of the International Electrotechnical Vocabulary (IEV) [IEC Publication 50(191)] as far as applicable. Terms requiring special definition or clarification are described below in the sense in which they are used in this standard. Unless otherwise stated they apply both to items of pure hardware and to items for which software is included or is predominant.

It is important to distinguish between the terms "failure intensity" (for repaired items) and "failure rate" (for non-repaired or one-shot items) in IEV Chapter 191.

3.1
reliability improvement

a process undertaken with the deliberate intention of improving the reliability performance by eliminating causes of systematic failures and/or by reducing the probability of occurrence of other failures (IEV 191-17-05.)

ADDITIONAL NOTE 1 The method described in this standard is to make corrective, modifications aimed at reducing systematic weaknesses.

ADDITIONAL NOTE 2 For any item there are limits to practicable and economic improvement and to achievable growth.

3.2
reliability growth

a condition characterized by a progressive improvement of a reliability performance measure of an item with time (IEV 191-17-04.)

3.3
weakness failure

a failure due to a weakness in the item itself when subjected to stresses within the stated capabilities of the item

NOTE A weakness may be either inherent or induced. (IEV 191-04-06.)

ADDITIONAL NOTE 1 A weakness is any imperfection (known or unknown) in an item, capable of causing one or more weakness failures.

ADDITIONAL NOTE 2 Each type of weakness is assumed to be statistically independent of all other such types.

3.4
systematic weakness

a weakness which can only be eliminated, or its effects reduced, by a modification of the design or manufacturing process, operational procedures, documentation or other relevant factors, or elimination of substandard batches of component parts

NOTE 1 Repair or replacement (or re-run in case of software) without modification is likely to lead to recurrent failures of a similar kind.

NOTE 2 Software weaknesses are always systematic.

3.5
residual weakness

a weakness which is not systematic

NOTE 1 In this case, risk of recurrent failure of a similar kind is negligible, within the expected test time scale.
NOTE 2 Software weaknesses cannot be residual.

3.6
relevant failure

a failure that should be included in interpreting test or operational results or in calculating the value of a reliability performance measure

NOTE The criteria for inclusion should be stated.
(IEV 191-04-13.)
ADDITIONAL NOTE The criteria for inclusion are stated in **7.2** below.

3.7
non-relevant failure

a failure that should be excluded in interpreting test or operational results or in calculating the value of a reliability performance measure

NOTE The criteria for exclusion should be stated.
(IEV 191-04-14.)
ADDITIONAL NOTE The criteria for exclusion are stated in **7.1** below.

3.8
systematic failure

a failure related in a deterministic way to a certain cause, which can only be eliminated by a modification of the design or of the manufacturing process, operational procedures, documentation or other relevant factors

NOTE 1 Corrective maintenance without modification will usually not eliminate the failure cause.
NOTE 2 A systematic failure can be induced at will by simulating the failure cause. (IEV 191-04-19.)
ADDITIONAL NOTE In this standard, a systematic failure is interpreted as a failure resulting from a systematic weakness.

3.9
residual failure

a failure resulting from a residual weakness

3.10
failure category A

a systematic failure for which management decides not to attempt corrective modification, due to cost, time, technological constraints or other reasons

3.11
failure category B

a systematic failure for which management decides to attempt corrective modification

3.12
instantaneous reliability measure

a reliability measure for an item at a given point (past or present) in a reliability growth programme

NOTE 1 The reliability measures commonly used are the (instantaneous) failure intensity (IEV 191-12-04) or the mean operating time between failures (MTBF) (IEV 191-12-09); as well as the (instantaneous) failure rate (IEV 191-12-02) or the mean time to failure (MTTF) (IEV 191-12-07).
NOTE 2 The values of these measures are estimated by a reliability growth model.

3.13
extrapolated reliability measure

the reliability measure for an item, predicted for a given future point in a reliability growth programme, where the corrective modifications are promptly introduced throughout the programme

NOTE 1 The definition of the modifier “extrapolated ...” in IEV Chapter 191, 191-18-03 applies here, but is restricted to time.
NOTE 2 The previous test conditions and corrective modification procedures are assumed to continue unchanged.
NOTE 3 The value of the reliability measure is estimated by a reliability growth model applied to the previous data and the same trend is assumed to apply also to the future period of the programme.
NOTE 4 The reliability measures commonly used are the (instantaneous) failure intensity (IEV 191-12-04) or the mean operating time between failures (MTBF) (IEV 191-12-09); as well as the (instantaneous) failure rate (IEV 191-12-02) or the mean time to failure (MTTF) (IEV 191-12-07).

3.14
projected reliability measure

the reliability measure predicted for an item as a consequence of the simultaneous introduction of a number-of corrective modifications

NOTE 1 The modifications are often introduced between two successive phases in the programme.
NOTE 2 The reliability measures commonly used are the (instantaneous) failure intensity (IEV 191-12-04) or the mean operating time between failures (MTBF) (IEV 191-12-09); as well as the (instantaneous) failure rate (IEV 191-12-02) or the mean time to failure (MTTF) (IEV 191-12-07).
NOTE 3 The values of these measures are estimated by a reliability growth model.

4 Basic concepts

In a programme of reliability growth, laboratory or field testing is used to stimulate the exposure of weaknesses and improve the reliability of a system, equipment, component part or similar item. When a failure occurs it shall be diagnosed, repair and/or replacement carried out and testing continued. Concurrently with testing, past failures shall be analysed to find their basic causes and, where appropriate, corrective modifications introduced into design or other procedures, resulting in progressive reliability growth. This procedure applies equally to pure hardware and to embedded software.

A reliability growth programme on non-repaired, or one-shot, items or component parts only, shall provide for successively modified samples, each of a more reliable design standard than before.

Reliability growth of software is independent of physical environment (e.g. temperature and humidity) but may be affected by other environments (e.g. use and maintenance) and is unaffected by reliability screening. However, estimates of reliability performance of both hardware and software can only be obtained through observation, monitoring and recording of failures. Consequently they are affected by the ability of performance testing to expose weaknesses during the programme. Such testing should therefore be as comprehensive as possible, in order to include all peculiar and unforeseen conditions or combinations of conditions which might arise in practical use.

4.1 Origins of weaknesses and failures

Weaknesses are normally unknown until revealed by failures. However, a weakness may be created long before the occurrence of an observable failure by an unconscious human error in some operation affecting an item. Alternatively, it may be inherent in material or due to a process not being under complete control.

Reliability growth is generally associated only with the reduction of the effects of systematic weaknesses. The sequence of events from the initial weakness to its elimination is shown in Figure 1 for both systematic and residual cases.

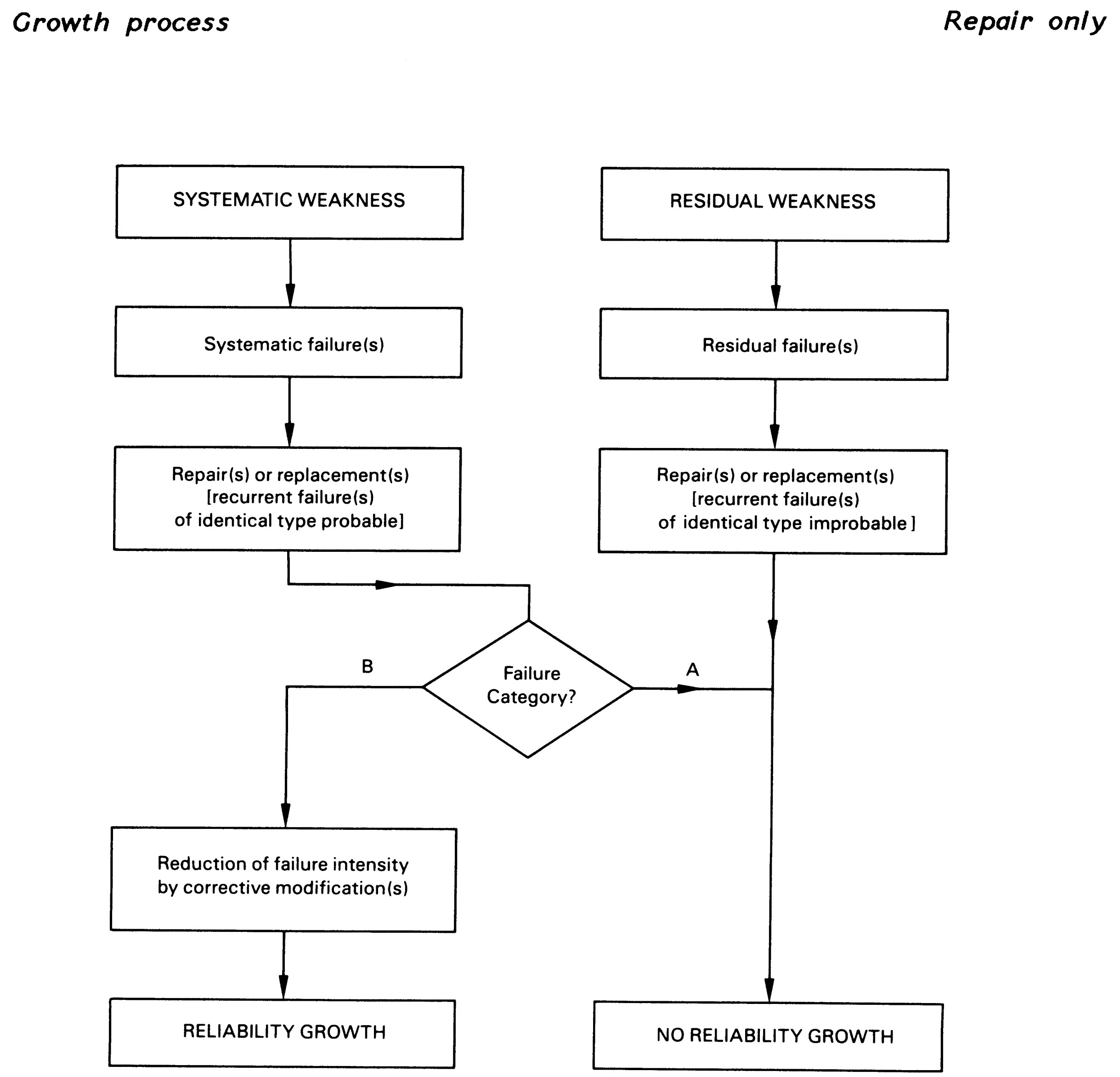

Figure 1 — Comparison between growth and repair processes

4.2 Systematic weaknesses

Systematic weaknesses are normally related to design or similar procedures.

The number of types of weaknesses present will have been influenced by:

— accuracy of specification of environment, or conditions of use;

— novelty, complexity or criticality of design, manufacturing processes or usage;

— constraints such as inadequate development or production time scales, stringency of finance, size, weight or performance;

— skill and level of training of personnel involved.

Systematic weaknesses can occur both in hardware and software and may have very wide effects because a single cause results in similar weaknesses being built into all items. Corrective modifications intended to eliminate systematic weaknesses may themselves include errors which introduce new systematic weaknesses.

4.3 Residual weaknesses

Residual weaknesses are normally related to manufacture of the item or of its parts. The factors in **4.2** will also contribute to the incidence of residual weaknesses but this can be reduced by personnel training, the learning process and quality control.

Residual weaknesses are found only in hardware. Unlike systematic weaknesses, their effects are restricted to single items. A significant proportion of the residual weaknesses present in an item can generally be eliminated by reliability screening, but others will remain and will result in failures at random intervals throughout the life of the item. Any extensive repairs, replacements or modifications involve the risk that new residual weaknesses may be introduced.

4.4 Failure patterns in reliability growth programmes

Since the failure intensity of the item is reduced by every successful modification, methods of estimation of failure intensity or of MTBF which assume constant failure intensity are not valid during the growth process.

This standard therefore outlines the principles of mathematical modelling for estimating the growth achieved and the projected reliability. Related techniques may be used in planning reliability improvement programmes by estimating the test time required to reach a specified reliability goal.

The accuracy of any such reliability evaluation method depends on how efficiently the test environment, monitoring procedures and failure reporting are controlled and the testing time is recorded. In this respect data from the laboratory are usually more dependable than those from the field or from "informal" test programmes. Modelling should not be attempted if there is doubt about the degree of control. However it is important to realize that, even if control is insufficient and modelling has to be abandoned, the processes of improvement described in this standard will always result in growth of reliability performance. A programme shall still be undertaken even if quantitative results cannot be estimated.

In Figure 2, the characteristic (1) shows an idealized staircase plot of the accumulated number of the first failures due to each type of systematic weakness, against test time. This characteristic appears exponential in shape, reflecting the finite number of types of inherent systematic weakness to which the curve tends. The characteristic (2) is of residual failures against their time of observation. This characteristic appears linear in form, after the end of the early failure period. The sum of characteristics (1) and (2) gives (3), the total relevant failures, tending ultimately to linearity. Recurrences of similar types of systematic failure may appear if corrective modification is delayed or is ineffectual.

The characteristics in Figure 2 depend upon the following assumptions:

— the early failure period is excluded; otherwise there would be nonlinearity at the start of characteristic (2);

— no new types of weakness are included which were created during the period of the programme, such as might be introduced during repair or modification;

— no failures due to normal or acceptable wearout are included;

— the environment, modes of operation and depth of testing remain constant throughout the programme. Any cycle in the test routine should be short and self-consistent;

— test time is accurately monitored.

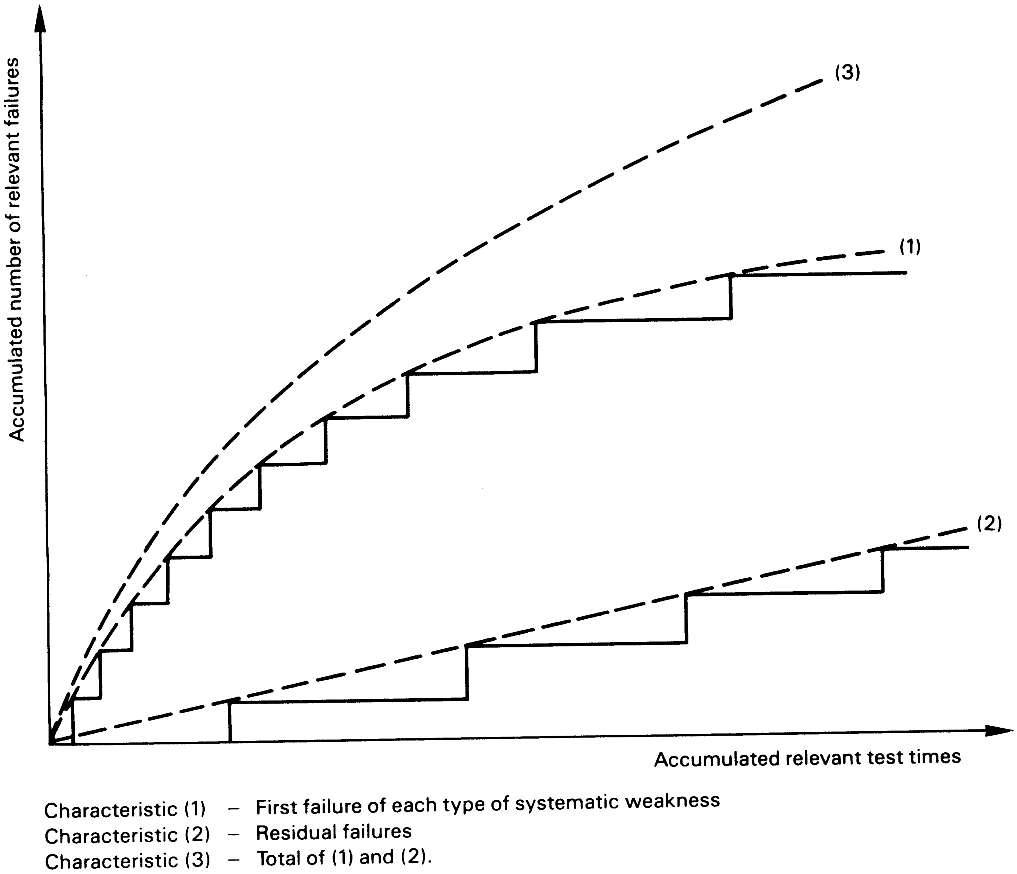

Figure 2 — Patterns of relevant failures with time

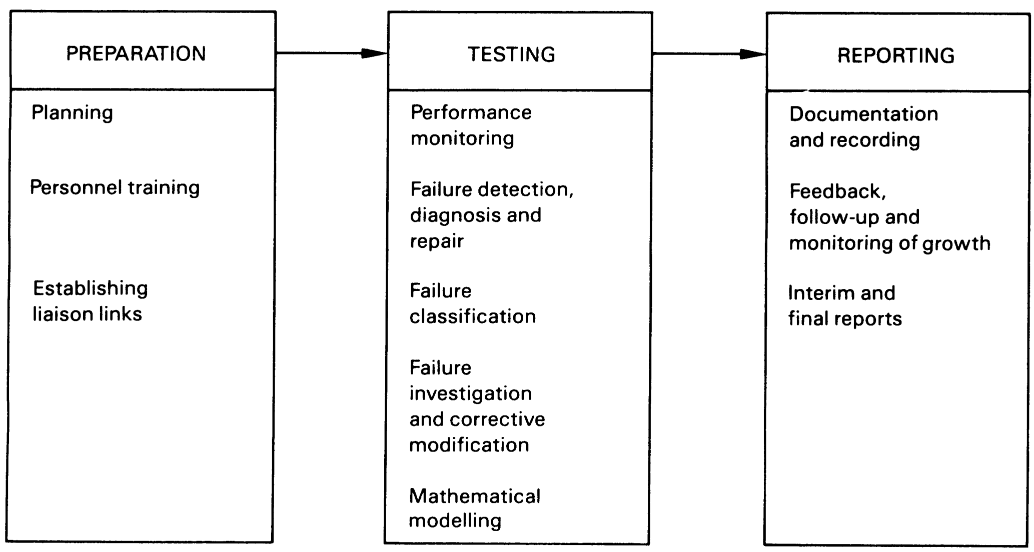

Figure 3 — Overall structure of a reliability growth programme

5 Management aspects

Management shall set up procedures for planning and executing a reliability growth programme and shall establish the important liaison links between the testing activity and those responsible for corrective modifications. Managerial guidelines are covered by IEC 300.

5.1 Procedures

Figure 3 shows the management procedures diagrammatically.

A period of preparation shall be scheduled for planning purposes (Clause **6**). This also allows all personnel to become acquainted with the equipment to be tested and for both formal and informal liaison links between the testing and design activities to be set up (**5.2**). Testing requirements are detailed in Clause **6**, failure classification in Clause **7** and corrective modification in Clause **8**. These three procedures are summarized in Figure 5.

Mathematical modelling (Clause **9**) should not commence until a statistically significant number of failures have occurred. Since estimation of growth is of less importance than the process of improvement, modelling shall be omitted if the model requirements are not fulfilled, rather than risk giving misleading results.

Reporting consists essentially of day-to-day detailed logging, feedback to design and reporting to the user. The elements of these activities appear in Clause **10**.

5.2 Liaison

Corrective modifications aimed at removing systematic weaknesses require a reliability engineer to progress them personally, since documentation alone will not trigger the necessary actions effectively. This engineer shall maintain close liaison with the personnel concerned with the various sources of failure information and with those responsible for elimination of systematic weaknesses.

The principal sources of failure data are:

- — reliability improvement testing;
- — reliability screening;
- — reliability demonstrations;
- — environmental qualification testing;
- — acceptance testing;
- — field trials;
- — operational use.

Reliability improvement testing shall be regarded as the most significant source, since it is dedicated to this purpose and requires close control of environment and data collection. However, other sources may provide useful background information in establishing failure categories. A computer data bank with searching and sorting facilities will enable similar types of failure from the various sources to be collated.

The areas of responsibility in which follow-up action may be needed include:

- — design and development;
- — parts suppliers and sub-contractors;
- — drawing offices;
- — specifications;
- — production planning;
- — manufacture;
- — reliability screening;
- — acceptance testing;
- — technical manuals;
- — operating and maintenance instructions;
- — training;
- — transportation and handling;
- — users.

Figure 4 illustrates the essential liaison links.

5.3 Manpower and costs

As the nature and scale of projects and items vary widely, only general guidance can be given. For small projects the reliability engineer indicated in **5.2** may be engaged only part time on a project, while in other cases he may require considerable supporting staff.

The estimated manpower should allow both for the reliability engineer and for the design effort needed to follow up weaknesses which would not have been known if there were no reliability growth programme. Analysis of failures and design of modifications will absorb significant effort in design and other appropriate areas.

Items to be tested and test equipment may afterwards be recoverable and may not contribute to the overall costs if they can be delivered or diverted to other uses after refurbishment. Unused spares are also recoverable.

5.4 Cost benefit

Investment in a reliability growth programme generally brings substantial savings in the cost of maintenance in the field over the life cycle of the total population of items. These savings depend on many factors, including the size of the population of items (or of the elements subject to failure within an item), the length of the life cycle, the average repair cost and the investment in maintenance facilities in the field.

6 Planning of reliability growth programmes

It is accepted that, within a practicable and economic time scale and effort, not all weaknesses will be eliminated. Some weaknesses, both systematic and residual, will remain and will determine the projected failure intensity. A typical total testing time for reliability improvement would be a few thousand item-hours, depending on the degree of improvement required.

Planning shall commence at a sufficiently early stage in the programme to allow for the timely delivery of all items and facilities which have to be procured. In preparing a test plan for a reliability growth programme, decisions shall be made concerning:

— number of items of each type to be tested and their design standards;

— test equipment (both standard and special);

— spare items (modules and parts);

— test conditions and environmental facilities;

— expected programme duration in operating time and calendar time;

— manpower for preparation, testing, liaison, repair, analysis, investigation and modification.

6.1 Number of items to be tested

Increasing the number of items tested simultaneously will make the sample more representative of the total population. Often, the simpler and less complex an item, the lower its cost and the higher its reliability. Therefore to produce a significant total number of failures in a reasonable time, more items should be tested. This is generally acceptable because of the lower cost and probably smaller physical size per item.

6.2 Testing by stressing

Because weaknesses are normally revealed only by the appearance of failures, reliability improvement programmes involve both the stimulation of failures and elimination of the systematic weaknesses which they expose. However, deliberate stimulation will usually apply in laboratory testing rather than in the field.

Selection of appropriate environmental stresses for stimulating failure should be guided by the considerations contained in IEC 605-1, IEC 605-2 and IEC 605-3, but in order to stimulate failures as quickly as possible the most severe environment and intensive use permitted by the design specification (for operation rather than storage) should be employed. For the same reason the item should also execute a repeated series of functions which are realistic but designed to give the maximum permissible stresses.

Environmental stresses and operational patterns need not be closely related to the conditions of use of an item but may be designed to give increased stimulation of latent weaknesses. However care should be taken not to introduce failure mechanisms untypical of normal use, which might render mathematical modelling unrealistic. Separate qualification tests in extreme environments, if carried out, may provide additional failure data. The type and severity of stimulation used may vary according to the level of assembly.

To ensure that all failures are detected, a comprehensive and frequent schedule of performance tests shall be carried out against the test specification. Where software is involved in the item, this testing schedule shall embrace all expected modes of operation and their likely combinations.

6.3 Programme duration

The time required to achieve a given target reliability can only be predicted on the basis of past experience (private or published) with the aid of reliability growth modelling. Mathematical models provide a means of predicting the number of relevant failures based on assumed model parameters estimated from previous programmes. This figure is then adjusted to allow for additional failures, i.e. non-relevant failures and repetitions of systematic failures from weaknesses still present. The average calendar time to repair and to make modifications is also estimated, together with a contingency for loss of facilities, sickness etc.

The calendar time for the total programme will be the sum of:

— total operating time required, converted to calendar time according to the maximum number of hours possible per week (or month);

— total downtime to repair all expected failures;

— total downtime for modifications to correct all expected systematic weaknesses;

— allowance of calendar time for contingencies.

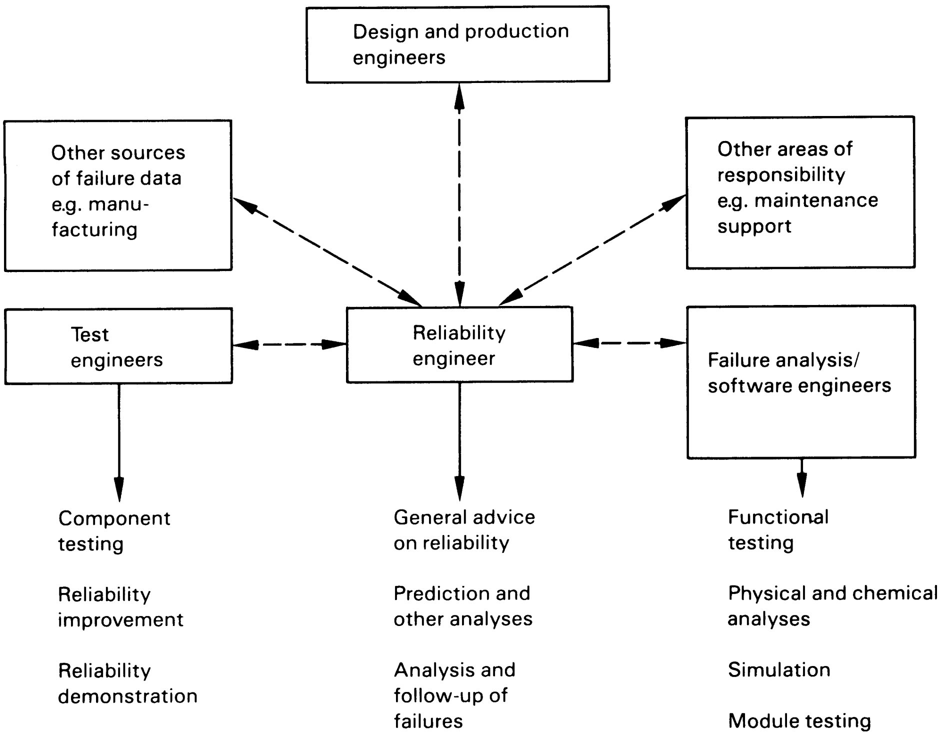

Figure 4 — Chart showing liaison links and functions

6.4 Planned growth and growth monitoring

A target reliability measure for the equipment being tested will normally be specified by the user.

In order to be able to assess progress in reliability growth towards this level during the programme, a planned growth curve may be prepared. This will show the reliability to be expected at specified points in the programme, in terms of calendar or test times. If the programme is conducted in distinct time phases, then these points may coincide with the ends of phases.

The planned overall growth pattern or "idealized growth curve" will normally be constructed from an accepted mathematical model (see Clause **9**) whose parameters reflect a realistic rate of growth based on past experience. If there are distinct phases, an individual target within each phase will be set, as shown in Figure 8. At the specified points in the programme, the actual growth as estimated by modelling will be compared with the planned growth (growth monitoring).

6.5 Special considerations for non-repaired or one-shot items and component parts

The principles which apply to a reliability growth programme for repairable items will also apply in general to a programme specially intended to improve the reliability of non-repaired or one-shot items or component parts. There are however some differences from an equipment programme. In this case the most common reliability measures are failure rate and MTTF.

Each sample of identical type items undergoing testing should be as large as possible. An item which fails need not be replaced provided the sample is not substantially reduced in size. In order to expose any further undiscovered inherent weaknesses, testing should continue in parallel with any systematic failure analysis. Systematic failures should normally be followed by corrective modification of the item, after which the entire sample under test is promptly upgraded to the modified version. Testing should recommence to verify the effectiveness of this and other modifications and to continue to reveal further unknown weaknesses.

Where the wearout of the item is significant, improvement may consist in extending this lifetime. Assessment by reliability growth modelling is unlikely to be practicable or dependable, since it is unlikely that there will be a statistically significant number of systematic weaknesses and modifications. However, if the samples are large enough, other methods such as Weibull analysis may be appropriate (see IEC 605-4).

7 Classification of failures

Classes of failure which do not result from those basic causes in design or construction, as described in Clause **4**, are non-relevant to corrective modification and to growth modelling and assessment. The first stage in classification is to identify and exclude failures which are non-relevant and the second stage is to subdivide the relevant failures into systematic and residual classes.

Classification requires engineering judgement, based on as much information as obtainable from investigations. Classification attempts to trace backwards the conceptual sequence described in **4.1**, i.e. from failure to weakness and to the nature of the original cause.

7.1 Classes of non-relevant failures

Non-relevant failures, in general, are covered by **9.3** of IEC Publication 605-1. Depending upon the special requirements of particular programmes (as defined in the appropriate specification or plan), some or all of the types of failure listed below may be classified as not requiring corrective modification and also as non-relevant to reliability growth assessment (Clause **9**).

If failures of any of the following types carry wider implications of unreliability, e.g. in interfaces, associated equipment or test gear, they may be relevant to corrective modification in these areas even if non-relevant to the main item in the programme.

7.1.1 ***Secondary failures — see 9.3.1 of IEC 605-1***

If considered to be systematic, then these failures will be relevant.

7.1.2 ***Misuse failures — see 9.3.2 of IEC 605-1***

If considered to be systematic, then these failures will be relevant.

7.1.3 ***Failure in process of correction, or already eliminated by design correction — see 9.3.3 of IEC 605-1***

When mathematical models are used for reliability growth assessment, individual requirements may or may not exclude these failures.

7.1.4 ***Identical intermittent failures***

After the first appearance of any one type, such failures may be non-relevant.

The underlying weakness is very likely to be systematic and hence relevant.

7.1.5 ***Need for operator adjustment or maintenance (normal operator use only)***

Failures which can be corrected by these means may be non-relevant.

If considered to be systematic, then these failures will be relevant.

7.1.6 ***Component parts failing to meet specification tests but satisfactory in their particular function***

If the overall performance of an equipment is unimpaired, such failures, which may be detected during investigation, may be non-relevant.

7.1.7 ***Failures after acceptable lifetime***

Failures of items subject to wearout, which fail after the specified minimum lifetime, may be non-relevant.

7.1.8 ***Failures during reliability screening***

These failures shall be non-relevant to reliability growth assessment. However, failures revealing new systematic weaknesses in reliability screening will always require investigation and possible corrective modification.

7.2 Classes of relevant failures

Relevant failures should be classified as either systematic or residual for two purposes:

- — in order to decide whether corrective modification is required;
- — for some methods of reliability growth modelling, to provide separate failure category inputs.

The following ground rules have been found to be useful in classifying failures:

— Systematic failures

Those which show after a physical, circumstantial or design analysis a condition or pattern of failure which may be expected to cause recurrence. This may be confirmed by actual recurrences after a long enough test time. For example, a component part found to be mildly over-stressed due to a design error might show recurrent failures over a sufficiently long period.

— Residual failures

Those which show no pattern of failure recurrence and whose causes do not suggest that recurrence is likely. For example, an apparent rogue component or chance error of workmanship.

Classifications shall be constantly reviewed as later events may provide new evidence to support reclassification, most often towards a systematic failure category B (see **7.3**).

7.3 Categories of relevant failures

Systematic failures should be classified as category A or B as explained below:

A — those not to be followed by corrective modifications because the expected results would not justify the cost, time or technical difficulty;

B — those which are followed by corrective modification aimed at preventing their recurrence.

8 Process of reliability improvement

Figure 5 shows the sequence of failure diagnosis, repair or replacement, classification and (where applicable) further investigation and corrective modification. The same general process will apply where the source of information is an informal programme or an activity having a different primary objective.

In order to minimize interruptions, the testing should be suspended at the time of a failure only long enough to permit diagnosis and repair or replacement. As far as possible, investigation of systematic failures and design of modifications should continue in parallel with testing, with the risk of course of repetitions of the same type of failure while the weakness still persists.

Systematic failures in category B will always be followed by corrective modification. When the modification has been devised it may be incorporated at the earliest convenient stopping-point (i.e. at the occurrence of another failure or other interruption). However, more efficient operation may be achieved if the programme is divided into distinct time phases and some (especially large-scale) modifications delayed until the end of each phase. Figure 8 shows an example of this.

Modules or other replacement units may be exchanged for spares to restore operation after a failure. This will allow the modification to be incorporated into the spare unit independently, with further downtime saving when it is re-introduced later. It is therefore an advantage to have a set of such spare units, but unless they include all previous modifications they should be used only temporarily.

The effectiveness of a modification will not be known until after a period of testing several times longer than the period to first failure due to a particular type of weakness. This will show not only whether the effects of a particular weakness have been successfully reduced or eliminated, but also whether alternative systematic weaknesses have been introduced. Any errors in workmanship or in new component parts, bringing new residual weaknesses, will also require a period of operation (similar to that for reliability screening) in order to expose them.

9 Mathematical modelling

This clause describes the modelling applicable where reliability is measured by failure intensity or by MTBF. For other measures of reliability, e.g. failure rate, MTTF or success ratio, alternative types of model should be used. Reliability growth modelling enables quantitative estimates to be made of the achieved and future reliability measures at the end of a reliability growth programme or at intermediate points, expressed in the following forms:

— the instantaneous failure intensity or MTBF at a given point in the programme;

— the extrapolated failure intensity or MTBF at some future point in the programme;

— the projected failure intensity or MTBF beyond the time when delayed modifications are incorporated or improvement ceases.

The instantaneous or extrapolated failure intensities are of greatest use while the programme is in progress and the projected measure is of the most value as a final estimate at the end of a phase or the end of the programme.

In addition, the following ratios may be estimated:

— the measures listed above, relative to the current measure at the start of the programme;

— the number of systematic weaknesses revealed, relative to the total inherent number as estimated by modelling;

— the number of systematic weaknesses acted upon by modification, relative to the total inherent number.

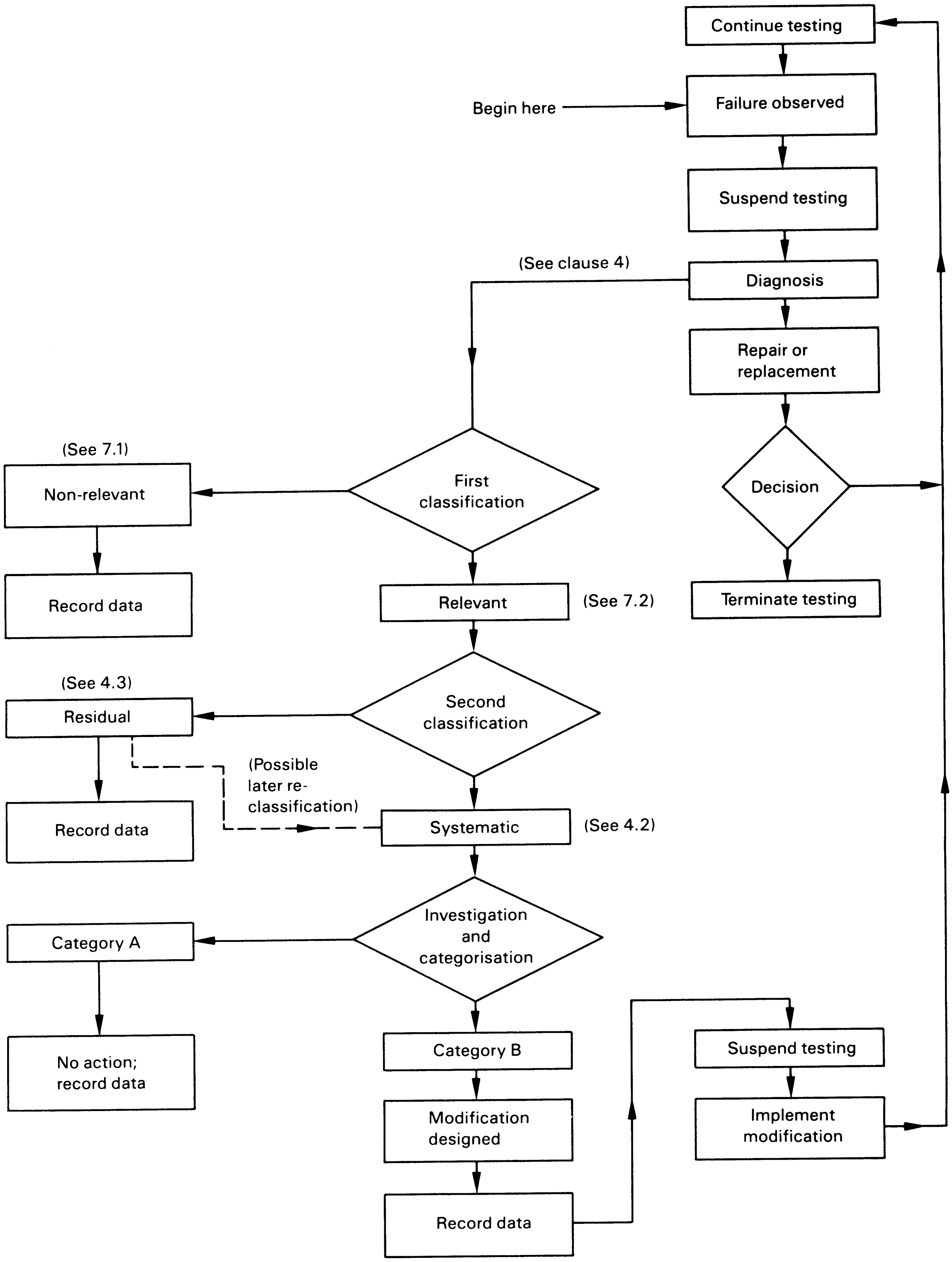

Figure 5 — Process of reliability improvement

The length of the early failure period may be estimated directly from the failure data, by visual examination of the failure/time characteristic or by other means. Both failures and times within this period shall be excluded from data used in reliability growth calculations.

9.1 Nature and objectives of modelling

Reliability growth models use mathematical functions which, when their variables or parameters have optimum values for a particular data set, closely reproduce the characteristics of that data set. Such functions and characteristics are best expressed in the same form as the original data set, which consists of accumulated numbers of relevant failures and corresponding accumulated relevant test times at each failure, as in Figure 2. The functions of the models may be either in continuous or discrete form. A discrete model represents failures more realistically as distinct steps, but often requires more stages in evaluation than a continuous model.

Choice of the model to be used involves a compromise between simplicity and evaluation and realism. Most models have not more than two parameters because a greater number complicates evaluation. Equations are solved in order to obtain maximum likelihood or least squares estimates of the parameters. By substitution of these values in the model function, the growth achievement is then derived, in the forms listed at the beginning of this clause.

Two important requirements for modelling are:

— there should be adequate data;

— the testing environment should follow a consistent pattern.

The models should not be regarded as infallible nor should they be applied without discretion, but used as statistical tools to aid engineering judgement.

9.2 Concepts of reliability measures as used in modelling

9.2.1 ***Instantaneous failure intensity***

As already shown by curve (3) of Figure 2, the characteristic of total relevant failures vs test time is generally of the form shown by the solid curve of Figure 6.

At any point in time, the instantaneous failure intensity is the slope of the tangent to the curve at that point. Figure 6 shows tangents drawn at the origin and at an intermediate point (t_1, n_1) of a reliability improvement programme, whose slopes represent instantaneous failure intensities of the item (or population of items). These slopes can be estimated after a curve fitting process employing a mathematical model.

However, if modifications to improve the reliability have been made in the later stages of the total testing period, the model may not have had a long enough period to reflect the resulting growth. Consequently, the true instantaneous failure intensity will be lower than that estimated. This is a special problem if most or all of the modifications have been delayed until the end of testing (or a particular phase of testing). This method of assessing reliability cannot then be used and only the projected failure intensity can be estimated as described below.

9.2.2 ***Extrapolated failure intensity***

Figure 6 shows the tangent drawn at point (t_2, n_2), whose slope represents the extrapolated failure intensity at that point, as estimated by extrapolation from point (t_1, n_1). It is assumed that the same model and parameters which applied to the failure data accumulated up to point (t_1, n_1) will continue to apply up to point (t_2, n_2) and that the testing conditions and prompt modification procedures are unchanged throughout the programme.

Thus the extrapolated failure intensity is a forward estimate or prediction of the level expected at some future stage or at the end of the programme. However it should be remembered that changing the test conditions or the modification procedure will invalidate the extrapolation.

9.2.3 ***Projected failure intensity***

The projected failure intensity is that which is expected to apply to an operation subsequent to a modification programme. A programme consisting of several modifications made simultaneously will cause a jump in reliability as shown in Figure 8 instead of continuous growth. If projected failure intensity is estimated at the end of the reliability growth programme, then it is relevant to operation in the field if the same environment can be assumed. Projection is more indirect and requires more engineering judgement than estimation of instantaneous or extrapolated failure intensity.

At the time of estimation there will be no evidence, resulting from tests, that all the modifications have improved the reliability to the extent intended and without introducing new types of weaknesses. It is found that few modifications are completely effective. An "improvement efficiency factor" is expressed as the expected fractional reduction in the failure intensity. This factor may be assigned by engineering judgement for each modification or as an overall average (typically 0.7).

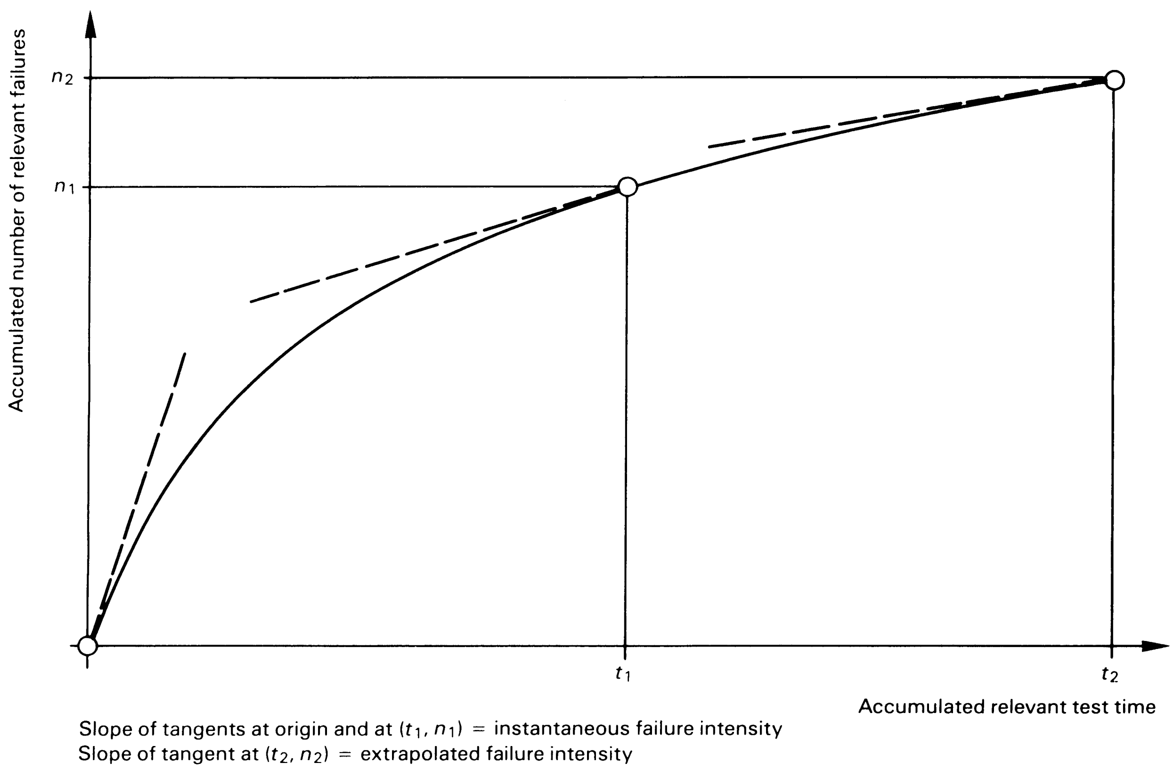

Figure 6 — Characteristic showing instantaneous and extrapolated failure intensities

The projection technique assumes that each identifiable type of systematic weakness has its own constant failure intensity after the early failure period which could be demonstrated if enough recurrent failures of this type were allowed. Of course with prompt and successful modifications, only the time to first failure of each type is available for the purpose of estimating this failure intensity.

The following steps are performed:

— Using the set of times to first failure of all systematic types, a model estimates the failure intensity of each known type of systematic failure.

— An improvement efficiency factor is applied.

— The total failure intensity due to all the systematic weaknesses not yet detected is estimated by the model.

— Because residual failure intensity is assumed constant, it is easily estimated directly by dividing the total number of residual failures by the accumulated relevant test time.

— The projected total failure intensity is estimated as the sum of the individual failure intensities due to the following weaknesses:

a) known systematic weaknesses, on which corrective modifications may or may not have been attempted;

b) undetected systematic weaknesses, predicted by the model, but not yet observed;

c) residual weaknesses.

Figure 7 illustrates these concepts.

These principles apply both to hardware and software, except that for software the residual failure intensity will always be nil.

9.2.4 *Other estimates*

The ratio of failure intensities as a measure of growth during a phase or throughout the programme can be measured by estimating the projected intensity and dividing it by the instantaneous value at the start of the programme. For models which estimate the total number of types of inherent systematic weakness (including those undetected) the fraction detected and acted upon is easily derived, for information. Further, the fraction which has resulted in modification is derived from the known number of category B failures. The degree of success of all the modifications and the accuracy of the arbitrary improvement efficiency factors can only be assessed from further testing or field experience.

10 Reporting and documentation

Documentation for a reliability growth programme shall take the form of:

a) A test plan, usually prepared by the manufacturer and approved by the user, detailing all the tasks comprising the reliability growth programme, the environment and the test facilities. These tasks shall include preparation and setting up, testing, monitoring, documentation and the procedure to be adopted after failure. A planned growth curve (see **6.4**) may be required.

b) A test specification, detailing regular monitoring of the functional performance of an item.

c) A daily log for recording test results, failures and other significant events.

d) A failure report for recording and notifying each failure, relevant or non-relevant. This should preferably be on a standard form used by the manufacturer for all sources of failure data and designed for easy entry of essential data into a databank.

e) A failure analysis report giving results of investigations and analyses and, where appropriate, actions arising from failures.

f) Interim reports at specified intervals to include, if required, plots comparing actual growth with planned growth (see Figure 8).

g) A final report describing the programme and presenting all essential results, actions and conclusions including reliability estimates by mathematical modelling.

NOTE Both d) and e) shall have a unique numbering system enabling each failure and its analysis to be related to each other and to the project or item concerned. Subsequent reports which update the situation shall reference all relevant previous reports.

Detailed information required for reports on general reliability testing is given in Clause **12** of IEC 605-1.

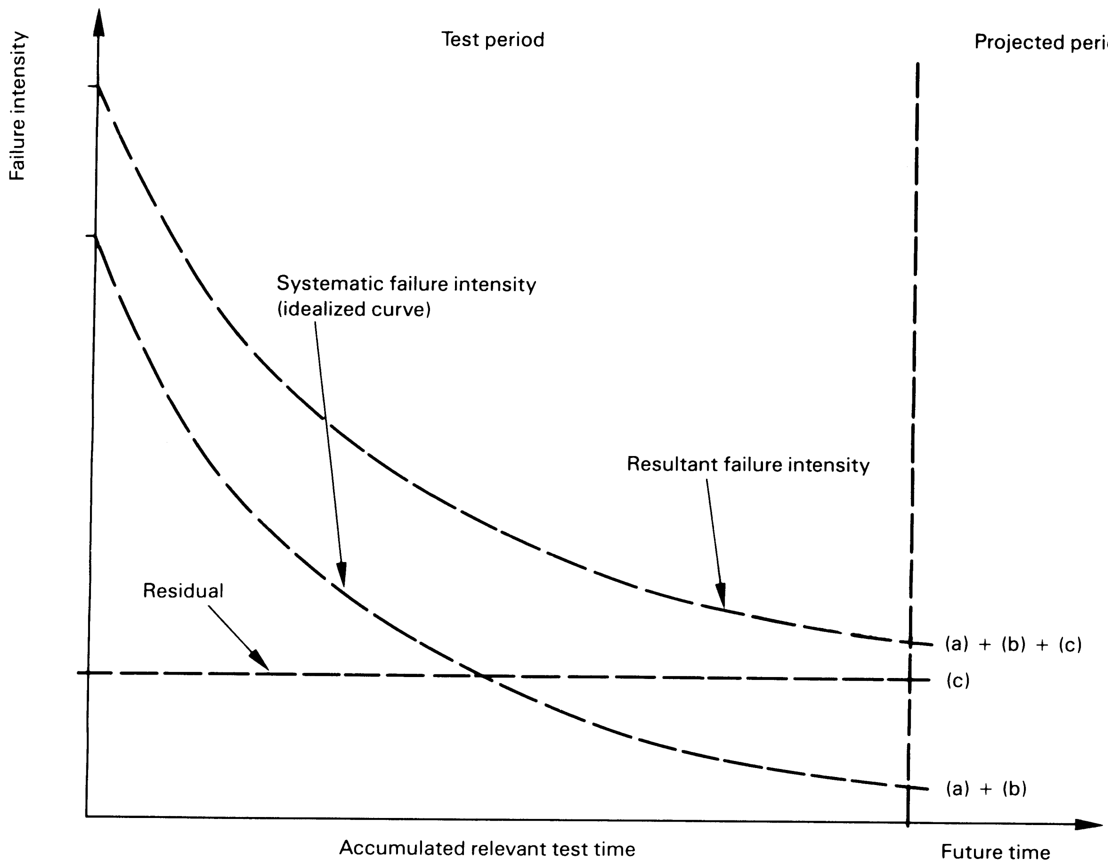

Figure 7 — Projected failure intensity estimated by modelling

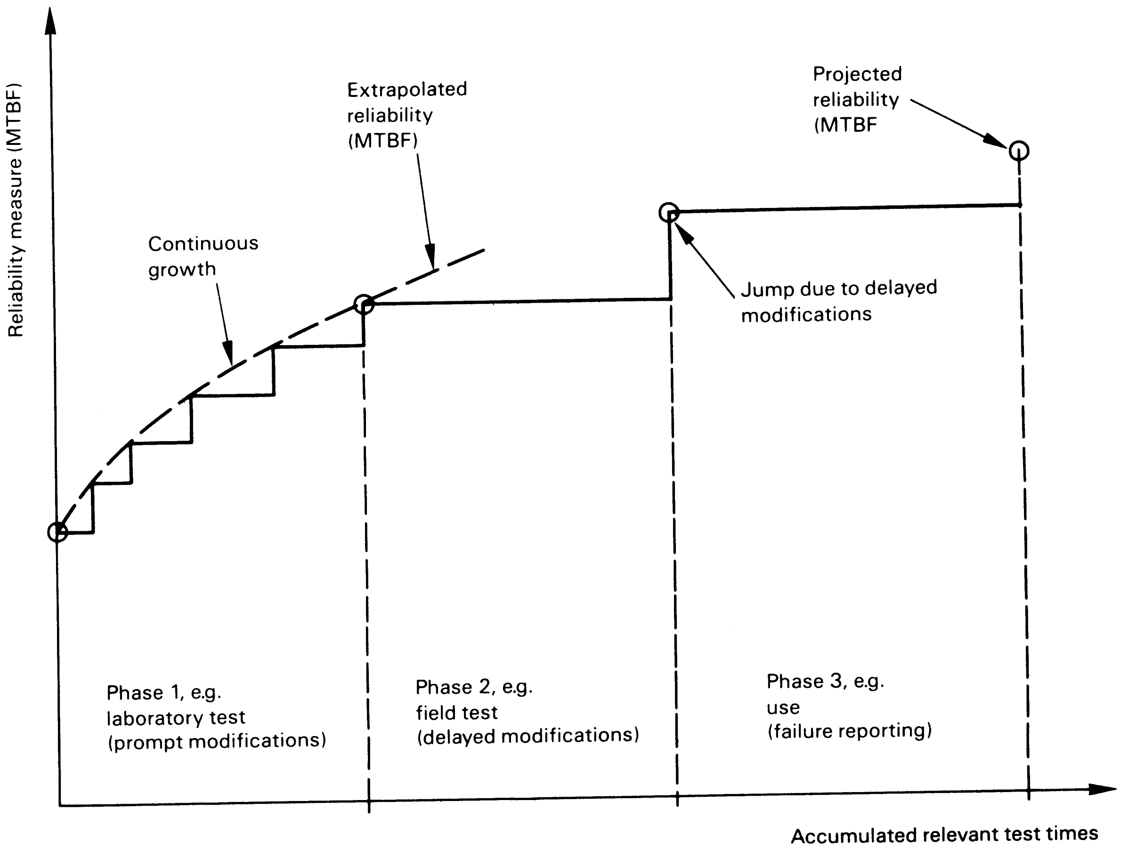

Figure 8 — Examples of growth curves and "jumps"

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Publication(s) referred to

See national foreword.

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