

Reliability of systems, equipment and components —

Part 5: Guide to failure modes, effects and criticality analysis (FMEA and FMECA)

Committees responsible for this British Standard

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- British Telecommunications plc
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- Cranfield Institute of Technology
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- Electricity Supply Industry in United Kingdom
- Electronic Components Industry Federation
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Foreword

This Part of BS 5760 has been prepared under the direction of the Quality, Management and Statistics Standards Policy Committee. It is based on IEC 812 published by the International Electrotechnical Commission (IEC). In the preparation of this Part of BS 5760, the committee has modified and extended the text of IEC 812 to clarify the nature of failure modes and effects analysis and criticality analysis and to present, and place particular emphasis upon, procedures for carrying out these analyses.

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.

Part 8¹⁾: 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.

NOTE 1 This British Standard makes reference to BS 4778, the Quality Vocabulary, and in particular to BS 4778-3, a glossary which contains definitions relating to reliability concepts applicable to the guide and it is essential that these definitions and concepts should be fully understood if this guide is to be interpreted correctly. For this reason it is recommended that BS 4778 should be read in conjunction with BS 5760.

NOTE 2 Chapter 191 of IEC 50, the International Electrotechnical Vocabulary, now deprecates the use of the terms “failure modes and effects analysis” and “failure modes, effects and criticality analysis” and favours the use of “fault modes and effects analysis” and “fault modes, effects and criticality analysis” respectively. However, the older terms have been retained in this standard in order to align it with the current version of IEC 812 which has been adopted by CEN.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 38, 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.

Section 1. General

0 Introduction

Failure modes and effects analysis (FMEA) and failure modes, effects and criticality analysis (FMECA) are methods of reliability analysis intended to identify failures which have consequences affecting the functioning of a system within the limits of a given application, thus enabling priorities for action to be set.

Generally, failures or failure modes of any component will affect system performance adversely. In the study of system reliability, safety and availability, both qualitative and quantitative analyses are needed and these complement one another. Quantitative analysis methods allow the calculation or prediction of performance measures of the system while fulfilling a specific task or in long-term operation under specific conditions. Typical measures denote reliability, safety, availability, failure rates, and mean time to failure (MTTF).

FMEA begins at the item or subassembly level for which the basic failure criteria (primary failure modes) are available. Starting from the basic failure characteristics of the elements and the functional structure of the system, the FMEA indicates the relationship between element failures and failures, malfunctions, operational constraints and degradation of performance or integrity of the system. To evaluate secondary and higher-order system and subsystem failures, the sequences of events in time may also need to be considered.

In a narrow sense, FMEA is limited to a qualitative analysis of failure modes of hardware, and does not include human errors and software errors, despite the fact that current systems are usually subject to both. In a wider sense, these factors should be included.

Criticality is a measure which combines the concepts of severity of consequences of failure and rate of occurrence or probability of occurrence of failure in a defined period. Severity is usually measured by placing a failure mode in one of a number of categories according to the consequences. Probability or rate of occurrence may also need to be dealt with in this way if numerical data are not available. Criticality is then measured by combining these indices in a defined manner.

1.1 Scope

This Part of BS 5760 describes failure modes and effects analysis (FMEA) and failure modes, effects and criticality analysis (FMECA), and gives guidance as to how they may be applied to achieve various objectives connected with the development of reliable designs, as follows:

- a) by describing the procedural steps necessary to perform an analysis (these are summarized in Appendix A);
- b) by identifying appropriate terms, assumptions, failure modes and criticality measures;
- c) by determining basic principles;
- d) by providing examples of the necessary worksheets;
- e) by providing recommendations for applications of FMEA and FMECA.

All the general qualitative considerations presented for FMEA also apply to FMECA. However, FMEA and FMECA are different in the sense that FMEA can be performed on its own, whereas criticality analysis has to be carried out in conjunction with an FMEA. FMECA also differs from FMEA in that the former is quantitative. For these reasons the two methods of analysis are dealt with separately in this standard. Examples of FMECA and FMEA are given in Appendix B.

While this Part of BS 5760 is concerned with the use of FMEA and FMECA for the pursuit of reliable designs, both FMEA and FMECA can also be used in the development of reliable processes. An example of this application is also given in Appendix B. (See example in B.4.)

NOTE 1 The titles of the publications referred to in this standard are listed on the inside back cover.

NOTE 2 Additional relevant publications are listed in Appendix C for information.

1.2 Definitions

For the purposes of this British Standard the definitions given in BS 4778-1, BS 4778-2 and BS 4778-3 apply, together with the following.

1.2.1

failure effect

the consequence of a failure mode in terms of the operation, function or status of a system

1.2.2

failure mode

the effect by which a failure is observed

1.2.3

criticality

a combination of the severity of an effect and the probability (or expected frequency) of its occurrence

Section 2. Failure modes and effects analysis

2.1 Introduction

2.1.1 General

FMEA and FMECA (see section 3) are important techniques for a reliability assurance programme. They can be applied to a wide range of problems which may occur in technical systems, and can be carried out in varying degrees of depth, or modified, to suit a particular purpose. The analysis is carried out in a limited way during the conception, planning, and definition phases and more fully in the design and development phase. It is however important to remember that the FMEA is only part of a reliability and maintainability programme which requires many different tasks and activities. FMEA is an inductive method of performing a qualitative system reliability or safety analysis from a low to a high level.

A thorough understanding of the system under analysis is essential prior to undertaking FMEA. Functional diagrams and other system drawings are normally necessary for this understanding. Reliability block diagrams, fault trees and/or state diagrams are then usually derived from these in order to carry out the analysis. In many instances the block diagram descriptions and block diagram failure descriptions are included in the FMEA format. Separate diagrams will be needed for the following:

- a) the way in which different criteria for system failure are determined;
- b) degradation of function or reduction in assurance of function;
- c) safety (as distinct from reliability or economic risk);
- d) alternative operational phases.

2.1.2 Purpose of the analysis

The reasons for undertaking FMEA (or FMECA) may include the following:

- a) to identify those failures which have unwanted effects on system operation, e.g. safety critical failures;
- b) to satisfy contractual conditions that an FMEA should be completed;
- c) where appropriate, to quantify the reliability and/or safety of the system;
- d) to allow improvements of the system's reliability and/or safety (e.g. by design or quality assurance actions);
- e) to produce aids to fault diagnosis;
- f) to allow improvement of the system's maintainability (by highlighting areas of risk or non-conformance for maintainability).

In view of these reasons the objectives of an FMEA (or FMECA) may include the following:

- 1) a comprehensive identification and evaluation of all the unwanted effects within the defined boundaries of the system being analysed, and the sequences of events brought about by each identified item failure mode, from whatever cause, at various levels of the system's functional hierarchy;
- 2) the determination of the significance (or criticality, see section 3) of each failure mode with respect to the system's correct function or performance and the impact on the reliability and/or safety of the process concerned;
- 3) a classification of identified failure modes according to relevant characteristics, including detectability, diagnosability, testability, item replaceability, compensating and operating provisions (repair, maintenance, logistics, etc.);
- 4) an estimation of measures of the significance and probability of failure.

NOTE This applies to criticality analysis only (see section 3).

2.1.3 Basic principles of FMEA

The following concepts are essential to FMEA:

- a) breakdown of the system into "elements";
- b) a diagram of the system's functional structure and identification of the various data which are needed to perform the FMEA;
- c) the failure mode concept (a part may have several failure modes or a failure mode may involve several parts);
- d) identification of new physical features or new requirements;
- e) the criticality concept and the measure to be used (if criticality analysis is required).

Further, it is essential to specify the existing links between the FMEA (and the FMECA) and other qualitative (and quantitative) analytical methods within the overall reliability programme.

Very few designs are wholly new. Most are to some extent developments of old designs. FMEA should use the information on existing systems and draw attention to the need for tests, etc. for the new parts.

2.2 Procedure

2.2.1 General

The wide variation in complexity of system designs and applications may require the development of highly individualized FMEA procedures consistent with the information available.

Traditionally there have been wide variations in the manner in which FMEA is conducted and presented. However, the analysis is usually done in a standard manner and presented on a worksheet that contains a core of essential information which can be developed and extended to suit the particular system or project to which it is applied. A typical example of a worksheet is shown in Figure 1.

The procedure consists of the following four main stages:

- a) preparatory definition of the system including the design, functional, operational, maintenance and environmental requirements;
- b) establishment of the basic principles and purposes of the FMEA and the form of its presentation;
- c) carrying out the FMEA using the appropriate worksheet designed according to a) and b);
- d) reporting of the complete analysis including any conclusions and recommendations made.

A more detailed consideration of the information needed is given in 2.4.

2.2.2 Preparation

At the commencement of an analysis the following preparations should be made.

- a) The analyst should have available the information listed in 2.4.2.2 to 2.4.2.7 that clearly defines the system to be analysed.
- b) It will usually be necessary for the analyst to translate the information into some form of functional, hierarchical or reliability block diagrams. An example of a functional diagram is shown in Figure 2. This diagram shows how the failure effects at the part level form the failure modes at the module level, the failure effects at the module level form the failure modes at the subsystem level, and so on. Such a representation of the system should explicitly identify the system's functional structure, the system boundary and the inputs and outputs crossing that boundary. Further information is given in 2.4.2.8 to 2.4.2.10.

2.2.3 FMEA principles

The following principles should be applied.

- a) Define clearly the purposes and uses of the FMEA as indicated in 2.1.2.
- b) Establish and define the relationships with other forms of reliability analysis with which the FMEA may subsequently be integrated. (See 2.3.5.)
- c) Define the scope of the FMEA in relation to the functional structure and hierarchical structure of the system as described by the block diagrams referred to in 2.4.2.10. It is essential to define the lowest level in the system's hierarchical structure at which the analysis will start. The guidance given in 2.3.4, 2.4.1.1 and 2.4.2.8 is especially important for this task.
- d) Define the format of the FMEA worksheet to suit the project requirements. The core information considered essential is as follows:
 - 1) the name of the item in the system being analysed;
 - 2) function performed by the item;
 - 3) identification number of the item;
 - 4) failure modes of the item;
 - 5) failure causes;
 - 6) failure effects on the system;
 - 7) failure detection methods;
 - 8) compensating provisions;
 - 9) severity of effects;
 - 10) remarks.

Other information required for the particular system and project needs to be defined by the analyst according to the purposes of the FMEA.

FMEA												
Indenture level:					Design by:			Prepared by:				
Sheet no:					Item:			Approved by:				
Mission phase:					Issue:			Date:				
Item ref.	Item description-function	Failure entry code	Failure mode	Possible failure causes	Symptom detected by	Local effect	Effect on unit output	Compensating provision against failure	Severity class	Failure rate (F/Mhr)	Data source	Recommendations and actions taken

Figure 1 — Example of the format of an FMEA worksheet

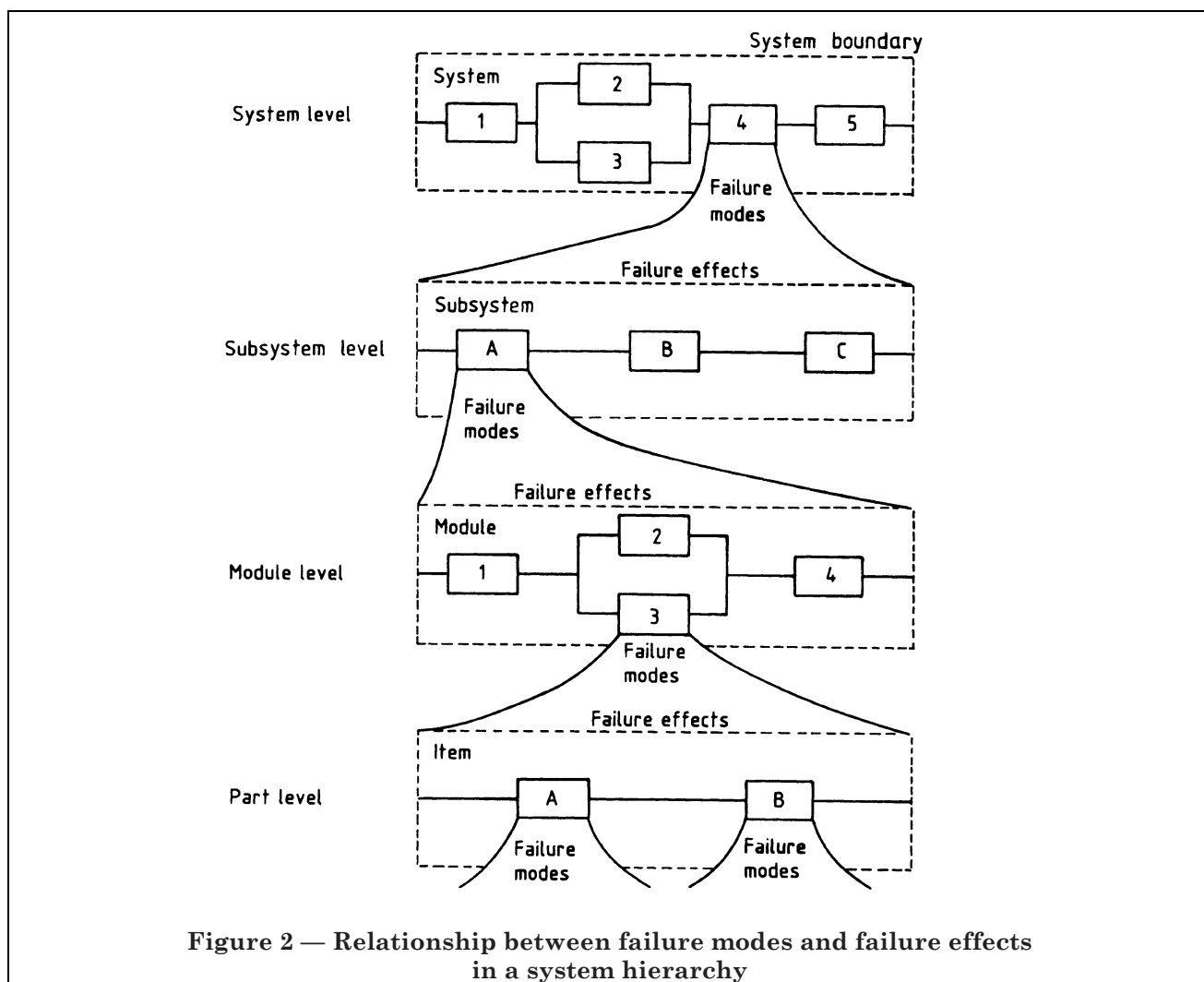


Figure 2 — Relationship between failure modes and failure effects in a system hierarchy

2.2.4 Analysis

2.2.4.1 Single stage

The usual requirement and purpose of an FMEA is to identify the effect of *all* failure modes of *all* constituent items at the lowest level in the system. To achieve this the worksheet should be used in the following manner.

- Identify all items in the system or subsystem, each of which is to have its failure modes and effects analysed. The system of identification by name and number should be such that no items will be omitted.
- Select the first item for analysis and enter the item name and identification number in the appropriate columns of the worksheet. Determine the function of that item in the system and enter that on the worksheet.
- Deduce all the possible failure modes of the item due to any possible cause and individually enter these modes on the worksheet. (Failure modes are discussed in 2.4.1.2.)

d) Postulate the most likely failure causes for each failure mode of the item and enter these on the worksheet.

It will usually not be possible to consider all possible causes because the range is so vast, but the most significant with regard to the item, the failure mode and the application should be identified.

e) Deduce the effects of the failure on the subsystem and system, as determined by the scope of the FMEA defined in accordance with 2.2.3.

f) Complete the remaining columns of the worksheet for the first failure mode of the first item.

g) Repeat c) to f) for all other failure modes of the first item.

h) Repeat b) to g) for all other items.

2.2.4.2 Multiple stages

If the FMEA is to be done in stages that each relate to separate levels in the system's hierarchical structure, the failure effects from the lower level become the failure modes at the next level up. This form of overall FMEA for large systems is recommended in 2.3.4. The analysis should then proceed as follows.

- a) Identify the lower level FMEAs that are appropriate for the next stage in the system FMEA according to the system's hierarchical structure defined by the block or functional diagrams [see 2.2.2 b)]. Where appropriate also include items defined as being at the lowest level in that part of the system structure.
- b) Perform the FMEA for each failure of each item at this higher level in the system structure as given in 2.2.4.1 b) to h).
- c) Repeat a) and b) above for any further higher levels in the system structure.

2.2.4.3 Worksheet remarks

The last worksheet entry should give any pertinent remarks to clarify other entries. Possible future actions such as recommendations for design improvements may be recorded and then amplified in the report. This column may also include the following:

- a) any unusual conditions;
- b) effects of redundant element failures;
- c) recognition of specially critical design features;
- d) any remarks to amplify the entry;
- e) references to other entries for sequential failure analysis;
- f) significant maintenance requirements;
- g) dominant failure causes;
- h) dominant failure effects;
- i) decisions taken, e.g. at design review.

2.2.4.4 Report of analysis

The report on the FMEA (or FMECA) may be included in a wider study or may stand alone. In either case, the report should include a summary and a detailed record of the analysis and the block or functional diagrams which define the system structure. The report should also contain a list of the drawings (including issue status) on which the FMEA is based.

The summary should contain a brief description of the method of analysis and the level to which it was conducted, the assumptions and the ground rules (see 2.4.1). In addition it should include listings of the following:

- a) recommendations for the attention of designers, maintenance staff, planners and users;
- b) failures which, when initially occurring alone, result in serious effects;
- c) failures which have no effect;
- d) design changes which have already been incorporated as a result of the FMEA (or FMECA).

2.3 Application

2.3.1 Field of application

FMEA is a method that is primarily adapted to the study of material and equipment failures and that can be applied to categories of systems based on different technologies (electrical, mechanical, hydraulic, etc.) and combinations of technologies. FMEA should also include the consideration of software and human performance where these are relevant to the reliability of the system. An FMEA can be a study for general use or it may be specific to particular pieces of equipment, to systems or to projects as a whole.

2.3.2 Application within a project

The user should determine how and for what purposes he uses FMEA within his own technical discipline. It may be used alone or to complement and support other methods of reliability analysis. The requirements for FMEA originate from the need to understand hardware behaviour and its implications for the operation of the system or equipment. The need for FMEA can vary widely from one project to another.

FMEA is the principal reliability engineering activity in support of the design review concept (see 4.2.1.4 of BS 5760-1:1985) and should be put into use from the very first steps of system and subsystem design. FMEA is applicable to all levels of system design but is most appropriate for lower levels where large numbers of items are involved and/or there is functional complexity. Special training of personnel performing FMEA is essential and they need the close collaboration of systems engineers and designers. The FMEA should be updated as the project progresses and as designs are modified. At the end of the project, FMEA is used to check the design and may be essential for demonstration of conformity of a designed system to the required standards, regulations, and user's requirements.

Information from the FMEA identifies priorities for statistical process control sampling and inspection tests during manufacture and installation and for qualification, approval, acceptance and start-up tests. It provides essential information for diagnostic and maintenance procedures for inclusion in handbooks.

In deciding on the extent and the way in which FMEA should be applied to an item or design, it is important to consider the specific purposes for which FMEA results are needed, the time phasing with other activities and the importance of establishing a predetermined degree of awareness and control over unwanted failure modes and effects. This leads to the planning of FMEA in qualitative terms at specified levels (system, subsystem, component, item) to relate to the iterative design and development process (see BS 5760-1).

To ensure that it is effective, the place of FMEA should be clearly established in the reliability programme, together with the time, manpower and other resources needed to make it effective. It is vital that FMEA is not abridged to save time and money. If time and money are short the FMEA should concentrate on those parts of the design which are new or are used in new ways. FMEA can be economically directed to areas identified as crucial by other methods of analysis, e.g. fault tree analysis (FTA).

2.3.3 Uses of FMEA

Some of the detailed applications and benefits of FMEA are listed below:

- a) to avoid costly modifications by the early identification of design deficiencies;
- b) to identify failures which, when they occur alone or in combination, have unacceptable or significant effects, and to determine the failure modes which may seriously affect the expected or required operation;

NOTE Such effects may include secondary failures.

- c) to determine the need for the following:
 - 1) redundancy;
 - 2) design improvement;
 - 3) more generous stress allowances (derating);
 - 4) screening of items;
 - 5) design of features that ensure that the system fails in a preferred failure mode, e.g. "fail-safe" outcomes of failures;
 - 6) selection of alternative materials, parts, devices, and components;
- d) to identify serious failure consequences and hence the need for changes in design and/or operational rules;

- e) to provide the logic model required to evaluate the probability or rate of occurrence of anomalous operating conditions of the system in preparation for criticality analysis;

- f) to disclose safety hazard and product liability problem areas, or non-compliance with regulatory requirements;

NOTE Frequently, separate studies will be required for safety, but overlap is inevitable and therefore cooperation is highly advisable.

- g) to ensure that the development test programme can detect potential failure modes;
- h) to focus upon key areas in which to concentrate quality control, inspection and manufacturing process controls;

- i) to assist in defining various aspects of the general maintenance strategy, such as:

- 1) establishing the need for data recording and condition monitoring during testing, checking-out and use;
- 2) provision of information for development of trouble-shooting guides;
- 3) establishing maintenance cycles which anticipate and avoid wear-out failures;
- 4) the selection of preventative or corrective maintenance schedules, facilities, equipment and staff;
- 5) selection of built-in test equipment and suitable test points;

- j) to provide a systematic and rigorous approach to the study of the installation in which the system is embedded;

- k) to facilitate or support the determination of test criteria, test plans and diagnostic procedures, for example: performance testing, reliability testing;

- l) to identify parts and assemblies requiring worst case analysis (frequently required for failure modes involving parameter drifts);

- m) to support the design of fault isolation sequences and to support the planning for alternative modes of operation and reconfiguration;

- n) to facilitate communication between the following:

- 1) general and specialized engineers;
- 2) equipment manufacturer and his suppliers;
- 3) system user and the designer or manufacturer;

- o) to enhance the analyst's knowledge and understanding of the behaviour of the equipment studied;

p) to provide designers with an understanding of the factors which influence the reliability of the system;

q) to provide a final document that is proof of the fact that (and of the extent to which) care has been taken to ensure that the design will meet its specification in service. (This is especially important in the case of product liability.)

2.3.4 Limitations and drawbacks

FMEA is extremely efficient when it is applied to the analysis of elements that cause a failure of the entire system or of a major function of the system. However, FMEA may be difficult and tedious for the case of complex systems that have multiple functions involving different sets of system components. This is because of the quantity of detailed system information that needs to be considered. This difficulty can be increased by the existence of a number of possible operating modes, as well as by consideration of the repair and maintenance policies.

FMEA can be a laborious and inefficient process unless it is judiciously applied. The uses to which the results are to be put subsequently should be defined and FMEA should not be included in requirements specifications indiscriminately.

Complications, misunderstandings and errors can occur when FMEA attempts to span several levels in a hierarchical structure if redundancy is applied in the system design.

It is therefore preferable for an FMEA to be restricted to relating two levels only in the hierarchical structure. For example, it is a relatively straightforward task to identify failure modes of items and to determine their effects on the assembly. These effects then become the failure modes at the next level up, e.g. the module, and so on. However, successful multi-level FMEAs are often carried out.

FMEA is applicable to all levels of a system but is most appropriate to lower levels where large numbers of items are involved and/or there is functional complexity.

2.3.5 Relationships with other methods

FMEA (or FMECA) can be used alone. As a systematic inductive method of analysis, FMEA is most often used to complement other approaches, especially deductive ones. At the design stage, it is often difficult to decide whether the inductive or deductive approach is dominant, as both are combined in processes of thought and analysis. Where levels of risk are identified in industrial facilities and systems, the inductive approach is preferred and therefore FMEA is an essential design tool. However, it should be supplemented by other methods. This is particularly the case when problems need to be identified and solutions need to be found in situations where multiple failures and sequential effects need to be studied. The method used first will depend on the project programme.

During the early design stages, where only functions, general system structure and subsystems have been defined, successful performance of the system can be depicted by a reliability block diagram or a failure path by a fault tree. However, to assist in drawing these diagrams of the system, an FMEA inductive process should be applied to the subsystems before they are designed. Under these circumstances, the FMEA approach cannot be a set procedure but is instead a thought process not readily expressed in a rigid tabular form. In general, when analysing a complex system involving several functions, numerous items and interrelations between these items, the FMEA proves to be essential but not sufficient.

Fault tree analysis (FTA) is a complementary deductive method. It traces the low level causes of a postulated high level failure. Though the logical analysis can be, and sometimes is, used for purely qualitative analysis of fault sequences it is usually a precursor to estimating the frequency of the postulated high level failure.

FTA concentrates on the logic of coincident (or sequential) and alternative events causing undesirable consequences. The FMEA format is more descriptive. Both methods have their uses in a full analysis for safety and reliability in a complex system. However, if the system is based mainly on series logic, with few redundancies and few functions, then FTA is an unnecessarily complicated way of presenting the logic and identifying the failure modes. In such cases FMEA and reliability block diagrams are adequate. In other cases where FTA is preferred, it still needs to be enhanced with descriptions of the failure modes and effects.