INTERNATIONAL STANDARD

IEC 60300-3-1

Second edition
2003-01

Dependability management –

Part 3-1: Application guide – Analysis techniques for dependability – Guide on methodology

Gestion de la sûreté de fonctionnement –

Partie 3-1:
Guide d'application –
Techniques d'analyse de la sûreté de fonctionnement –
Guide méthodologique

Reference number
IEC 60300-3-1:2003(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE XA

For price, see current catalogue

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

DEPENDABILITY MANAGEMENT –

Part 3-1: Application guide – Analysis techniques for dependability – Guide on methodology

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60300-3-1 has been prepared by IEC technical committee 56: Dependability.

This second edition cancels and replaces the first edition, published in 1991, and constitutes a full technical revision. In particular, the guidance on the selection of analysis techniques and the number of analysis techniques covered has been extended.

The text of this standard is based on the following documents:

FDIS	Report on voting
56/825/FDIS	56/840/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until 2007. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

INTRODUCTION

The analysis techniques described in this part of IEC 60300 are used for the prediction, review and improvement of reliability, availability and maintainability of an item.

These analyses are conducted during the concept and definition phase, the design and development phase and the operation and maintenance phase, at various system levels and degrees of detail, in order to evaluate, determine and improve the dependability measures of an item. They can also be used to compare the results of the analysis with specified requirements.

In addition, they are used in logistics and maintenance planning to estimate frequency of maintenance and part replacement. These estimates often determine major life cycle cost elements and should be carefully applied in life cycle cost and comparative studies.

In order to deliver meaningful results, the analysis should consider all possible contributions to the dependability of a system: hardware, software, as well as human factors and organizational aspects.

DEPENDABILITY MANAGEMENT –

Part 3-1: Application guide – Analysis techniques for dependability – Guide on methodology

1 Scope

This part of IEC 60300 gives a general overview of commonly used dependability analysis techniques. It describes the usual methodologies, their advantages and disadvantages, data input and other conditions for using various techniques.

This standard is an introduction to selected methodologies and is intended to provide the necessary information for choosing the most appropriate analysis methods.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050(191):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 191: Dependability and quality of service*

IEC 60300-3-2:1993, *Dependability management – Part 3: Application guide – Section 2: Collection of dependability data from the field*

IEC 60300-3-4:1996, *Dependability management – Part 3: Application guide – Section 4: Guide to the specification of dependability requirements*

IEC 60300-3-5:2001, *Dependability management – Part 3-5: Application guide – Reliability test conditions and statistical test principles*

IEC 60300-3-10:2001, *Dependability management – Part 3-10: Application guide – Maintainability*

IEC 60706-1:1982, *Guide on maintainability of equipment – Part 1: Sections One, Two and Three – Introduction, requirements and maintainability programme*

IEC 60706-2:1990, *Guide on maintainability of equipment – Part 2: Section Five – Maintainability studies during the design phase*

IEC 60812:1985, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*

IEC 61078:1991, *Analysis techniques for dependability – Reliability block diagram method*

IEC 61165:1995, *Application of Markov techniques*

IEC 61709:1996, *Electronic components – Reliability – Reference conditions for failure rates and stress models for conversion*

IEC 61882:2001, *Hazard and operability studies (HAZOP studies) – Application guide*

ISO 9000:2000, *Quality management systems – Fundamentals and vocabulary*

3 Definitions

For the purposes of this part of IEC 60300, the definitions given in IEC 60050(191), some of which are reproduced below, together with the following definitions, apply.

3.1
item, entity
any part, component, device, sub-system, functional unit, equipment or system that can be individually considered

NOTE An item may consist of hardware, software or both, and may also in particular cases, include people.

[IEV 191-01-01]

3.2
system
set of interrelated or interacting elements

[ISO 9000, 2000]

NOTE 1 In the context of dependability, a system will have

a) a defined purpose expressed in terms of required functions, and

b) stated conditions of operation/use.

NOTE 2 The concept of a system is hierarchical.

3.3
component
item on the lowest level considered in the analysis

3.4
allocation
procedure applied during the design of an item intended to apportion the requirements for performance measures for an item to its sub-items according to given criteria

3.5
failure
termination of the ability of an item to perform a required function

NOTE 1 After failure the item has a fault.

NOTE 2 ‘Failure’ is an event, as distinguished from ‘fault’, which is a state.

[IEV 191-04-01]

3.6
fault
state of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources

NOTE A fault is often the result of a failure of the item itself, but may exist without prior failure.

[IEV 191-05-01]

4 Basic dependability analysis procedure

4.1 General procedure

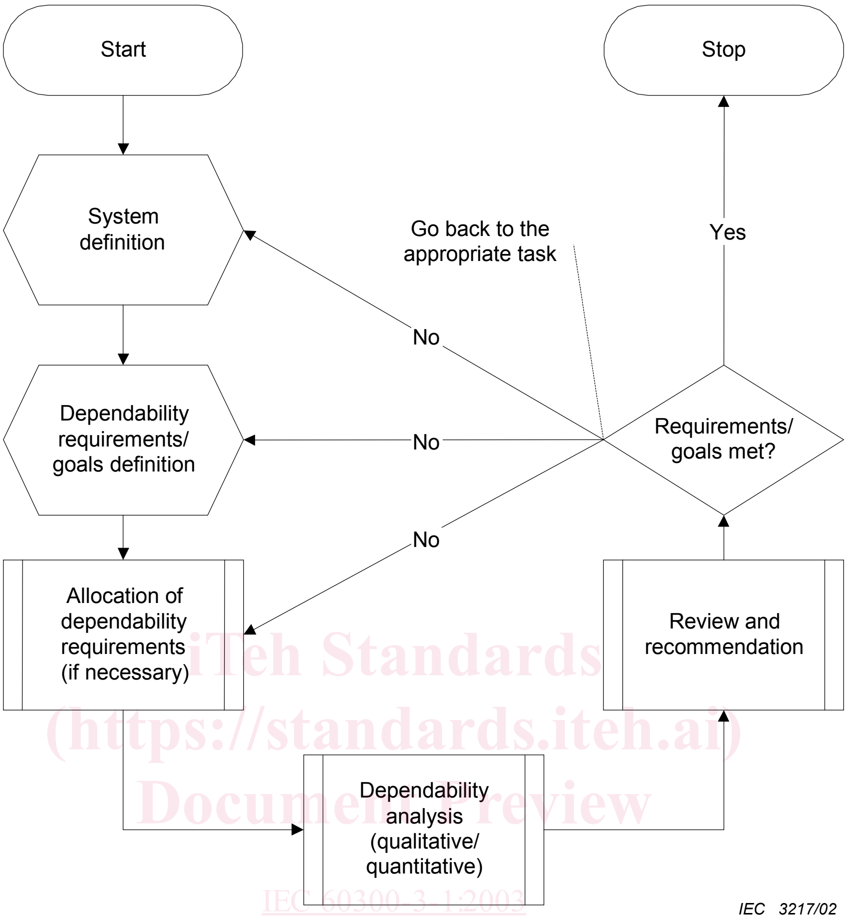
Start
Stop
System definition
Go back to the appropriate task
Yes
No
Dependability requirements/ goals definition
No
Requirements/ goals met?
No
Allocation of dependability requirements (if necessary)
Review and recommendation
Dependability analysis (qualitative/ quantitative)
IEC 3217/02

Figure 1 – General dependability analysis procedure

A general dependability analysis procedure consists of the following tasks (as applicable):

a) System definition

Define the system to be analysed, its modes of operation, the functional relationships to its environment including interfaces or processes. Generally the system definition is an input from the system engineering process.

b) Dependability requirements/goals definition

List all system reliability and availability requirements or goals, characteristics and features, together with environmental and operating conditions, as well as maintenance requirements. Define system failure, failure criteria and conditions based on system functional specification, expected duration of operation and operating environment (mission profile and mission time). IEC 60300-3-4 should be used as guidance.

c) Allocation of dependability requirements

Allocate system dependability requirements or goals to the various sub-systems in the early design phase when necessary.

d) Dependability analysis

Analyse the system usually on the basis of the dependability techniques and relevant performance data.

1) Qualitative analysis
   - Analyse the functional system structure.
   - Determine system and component fault modes, failure mechanisms, causes, effects and consequences of failures.
   - Determine degradation mechanism that may cause failures.
   - Analyse failure/fault paths.
   - Analyse maintainability with respect to time, problem isolation method, and repair method.
   - Determine the adequacy of the diagnostics provided to detect faults.
   - Analyse possibility for fault avoidance.
   - Determine possible maintenance and repair strategies, etc.
2) Quantitative analysis
   - Develop reliability and/or availability models.
   - Define numerical reference data to be used.
   - Perform numerical dependability evaluations.
   - Perform component criticality and sensitivity analyses as required.

e) Review and recommendations

Analyse whether the dependability requirements/goals are met and if alternative designs may cost effectively enhance dependability. Activities may include the following tasks (as appropriate):

- Evaluate improvement of system dependability as a result of design and manufacture improvement (e.g. redundancy, stress reduction, improvement of maintenance strategies, test systems, technological processes and quality control system).

  NOTE 1 The inherent dependability performance measures can be improved only by design. When poor measured values are observed due to bad manufacturing processing, from the operating point of view, observed dependability performance measures can be enhanced by improving the manufacturing process.
- Review system design, determine weaknesses and critical fault modes and components.
- Consider system interface problems, fail-safe features and mechanisms, etc.
- Develop alternative ways for improving dependability, e.g. redundancy, performance monitoring, fault detection, system reconfiguration techniques, maintenance procedures, component replaceability, repair procedures.
- Perform trade-off studies evaluating the cost and complexity of alternative designs.
- Evaluate the effect of manufacturing process capability.
- Evaluate the results and compare with requirements.

NOTE 2 The general procedure summarizes, from an engineering point of view, the specific dependability programme elements from IEC 60300-2, which are applicable for dependability analysis: dependability specifications, analysis of use environment, reliability engineering, maintainability engineering, human factors, reliability modelling and simulation, design analysis and product evaluation, cause-effect impact and risk analysis, prediction and trade-off analysis.

4.2 Dependability analysis methods

The methods presented in this standard fall into two main categories:

- methods which are primarily used for dependability analysis;
- general engineering methods which support dependability analysis or add value to design for dependability.

The usability of the dependability analysis methods within the general dependability analysis tasks of the general analysis procedure is given in Table 1. Table 2 gives more detailed characteristics. The methods are explained briefly in Annex A.

Table 1 – Use of methods for general dependability analysis tasks

Analysis method	Allocation of dependability requirements/goals	Qualitative analysis	Quantitative analysis	Review and recommen-dations	Annex
Failure rate prediction	Applicable for serial systems without redundancy	Possible for maintenance strategy analysis	Calculation of failure rates and MTTF for electronic components and equipment	Supporting	A.1.1
Fault tree analysis	Applicable, if system behaviour is not heavily time- or sequence-dependent	Fault combinations	Calculation of system reliability, availability and relative contributions of subsystems to system unavailability	Applicable	A.1.2
Event tree analysis	Possible	Failure sequences	Calculation of system failure rates	Applicable	A.1.3
Reliability block diagram analysis	Applicable, for systems where independent blocks can be assumed	Success paths	Calculation of system reliability, availability	Applicable	A.1.4
Markov analysis	Applicable	Failure sequences	Calculation of system reliability, availability	Applicable	A.1.5
Petri net analysis	Applicable	Failure sequences	To provide the system description for Markov analysis	Applicable	A.1.6
Failure modes and effects (and criticality) analysis; FME(C)A	Applicable for systems where independent single failure is predominant	Effects of failures	Calculation of system failure rates (and criticality)	Applicable	A.1.7
HAZOP studies	Supporting	Causes and consequences of deviations	Not applicable	Supporting	A.1.8
Human reliability analysis	Supporting	Impact of human performance on system operation	Calculation of error probabilities for human tasks	Supporting	A.1.9
Stress-strength analysis	Not applicable	Usable as a means of fault avoidance	Calculation of reliability for (electro) mechanical components	Supporting	A.1.10
Truth table (structure function analysis)	Not applicable	Possible	Calculation of system reliability, availability	Supporting	A.1.11
Statistical reliability methods	Possible	Impact of faults	Quantitative estimation of reliability with uncertainties	Supporting	A.1.12

NOTE The particular wording in the table is used as follows:

'Applicable' means that the method is generally applicable and recommended for the task (possibly with the mentioned restrictions).

'Possible' means that the method may be used for this task but has certain drawbacks compared to other methods.

'Supporting' means that the method is generally applicable for a certain part of the task but not as a stand-alone method for the complete task.

'Not applicable' means that the method cannot be used for this task.

Among the supporting or general engineering methods are (the list being not necessarily exhaustive):

- maintainability studies (covered by IEC 60300-3-10 in general and IEC 60706-2 in particular);
- sneak circuit analysis (A.2.1);
- worst case analysis (A.2.2);
- variation simulation modelling (A.2.3);
- software reliability engineering (A.2.4);
- finite element analysis (A.2.5);
- parts derating and selection (A.2.6);
- Pareto analysis (A.2.7);
- cause and effect diagrams (A.2.8);
- failure reporting and corrective action system (A.2.9)

It should also be noted that the methods are named and understood in the sense of the relevant IEC standards (where they exist). The following methods have not been included as separate methods because they are derived from or closely related to primary methods:

- cause/consequence analysis is a combination of ETA and FTA;
- dynamic FTA is an extension of FTA, where certain events are expressed by Markov sub-models;
- functional failure analysis is a particular type of functional FMEA;
- binary decision diagrams are mainly used as an efficient representation of fault trees.

4.3 Dependability allocations

Defining the dependability requirements for sub-systems is an essential part of the system design work. The objective of this task is to find the most effective system architecture to achieve the dependability requirements (and thus contribute to the feasibility study). As dependability is the collective term for reliability, availability and maintainability, an allocation for each of these characteristics is necessary. However as allocation techniques for all three characteristics are similar, the collective term dependability is used in this instance.

The first step is to allocate the dependability requirements of the overall system to sub-systems, depending on the complexity of these sub-systems based on experience with comparable sub-systems. If the requirements are not met by the initial design, allocation and/or design shall be repeated. Allocation is also often made on the basis of considerations such as complexity, criticality, operational profile and environmental condition.

Since dependability allocation is normally required at an early stage when little or no information is available, the allocation should be updated periodically.

Allocation, sometimes called apportionment, of system dependability to the sub-system and assembly levels is necessary early in the product definition phase in order to

- check the feasibility of dependability requirements for the system,
- establish realistic dependability design requirements at lower levels,
- establish clear and verifiable dependability requirements for sub-suppliers.

When accomplishing dependability allocation, the following steps are needed:

– Analyse the system and identify areas where design is known and information concerning values of dependability characteristics is available or can be readily assessed.

– Assign the appropriate weights and determine their contribution to the top-level system dependability requirement. The difference constitutes the portion of the dependability requirement that can be allocated to the other areas.

Dependability allocation has the following benefits:

– It provides a way for the product development to progress and to understand the dependability goals relationships between system and their items (e.g. sub-systems, equipment, components).

– It considers dependability equally with other design parameters such as cost and performance characteristics.

– It provides specific dependability goals for the suppliers to meet for their deliveries, which, in turn, leads to improved design and procurement procedures.

– It may lead to optimum system dependability because it considers such factors as complexity, criticality and effect of operational environment.

On the other hand, some limitations should be noted:

– Assumption is often made that the items of a system are independent, i.e. failure of one item does not affect others. Since this assumption is often not valid, this limitation reduces the benefits of the method.

– Allocation of redundant systems is more complex. In these cases, it is appropriate to use an iterative method to check whether dependability goals for the system can be reached, for example the fault tree method.

4.4 Dependability analysis

4.4.1 Categories of methods

Dependability analysis methods, which are explained briefly in Annex A, can be classified by the following categories with regard to their main purpose:

a) methods for fault avoidance, e.g.

   1) parts derating and selection,

   2) stress-strength analysis;

b) methods for architectural analysis and dependability assessment (allocation), e.g.

   1) bottom-up method (mainly dealing with effects of single faults),

      – event tree analysis (ETA),

      – failure mode and effects analysis (FMEA),

      – hazard and operability study (HAZOP);

   2) top-down methods (able to account for effects arising from combination of faults)

      – fault tree analysis (FTA),

      – Markov analysis,

      – Petri net analysis,

      – truth table (structure function analysis),

      – reliability block diagrams (RBD);

c) methods for estimation of measures for basic events, e.g.

- failure rate prediction,
- human reliability analysis (HRA),
- statistical reliability methods,
- software reliability engineering (SRE).

Another distinction is whether these methods work with sequences of events or time-dependent properties. If this is taken into account, the following comprehensive categorization results:

	Bottom-up (single fault)	**Top-down (multiple faults)**
Sequence dependent	Event-tree analysis	Markov, Petri, truth table
Sequence independent	FMEA, HAZOP	FTA, RBD

These analysis methods allow for the evaluation of qualitative characteristics as well as estimation of quantitative ones in order to predict long-term operating behaviour. It should be noticed that the validity of any result is clearly dependent on the accuracy and correctness of the input data for the basic events.

However, no single dependability analysis method is sufficiently comprehensive and flexible to deal with all the possible model complexities required to evaluate the features of practical systems (hardware and software, complex functional structures, various technologies, repairable and maintainable structures, etc.). It may be necessary to consider several complementary analysis methods to ensure proper treatment of complex or multi-functional systems.

In practice, a composite approach, with top-down and bottom-up analysis complementing one another, has proven to be very effective, in particular with respect to ensuring the completeness of the analysis.

4.4.2 Bottom-up methods

The starting point of any bottom-up method is to identify failure modes at the component level. For each failure mode, the corresponding effect on performance is deduced for the appropriate system level. This “bottom-up” method is rigorous in identifying all single-failure modes, because it can rely on parts lists or other checklists. In the initial stages of development, the analysis may be qualitative in nature and deal with functional failures. Later, as the component design details become available a quantitative analysis can be undertaken.

4.4.3 Top-down methods

At first, the undesirable single event or system success at the highest level of interest (the top event) should be defined. The contributory causes of that event at all levels are then identified and analysed.

The starting point of the top-down approach is to proceed from the highest level of interest, that is, the system or sub-system level, to successively lower levels in order to identify undesirable system operations.

The analysis is performed at the next lowest system level to identify any failure and its associated failure mode, which could result in the failure effect as originally identified. For each of these second level failures, the analysis is repeated by tracing back along the functional paths and relationships to the next lowest level. This process is continued as far as the lowest level desired.