

# Maintainability of equipment —

## Part 2: Maintainability requirements and studies during the design and development phase

The European Standard EN 60706-2:2006 has the status of a British Standard

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## National foreword

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**Maintainability of equipment**  
**Part 2: Maintainability requirements and studies**  
**during the design and development phase**  
(IEC 60706-2:2006)

Maintenabilité de matériel  
Partie 2 : Exigences et études de  
maintenabilité pendant la phase de  
conception et de développement  
(CEI 60706-2:2006)

Instandhaltbarkeit von Geräten  
Teil 2: Instandhaltbarkeitsanforderungen  
und Studien in der Entwicklungsphase  
(IEC 60706-2:2006)

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## **Foreword**

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## **Endorsement notice**

The text of the International Standard IEC 60706-2:2006 was approved by CENELEC as a European Standard without any modification.

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## INTRODUCTION

Maintainability is a characteristic that defines the ease with which an item can be maintained and supported during its period of use. Maintainability has to be built into an item during the design and development phase and it is therefore important that maintainability requirements be established as part of the initial specification.

The IEC 60706 series of standards is intended to give guidance on how a designer should best incorporate high standards of maintainability into a product so that the cost of maintenance is reduced to an acceptable level. It is also important to ensure that the necessary maintenance can be undertaken to keep the product in a safe condition and that it can be operated to its required performance.

This International Standard gives an introduction to the concept of maintainability, and guidance as to how maintainability can be incorporated into specifications and contracts and how maintainability should be considered as part of the design process. It forms part of a hierarchy of standards on dependability as described below.

IEC 60300-1 and IEC 60300-2 are the IEC top-level standards that provide guidance on how to incorporate dependability, including reliability, availability and maintainability, into manufactured products. IEC 60300-3-10 is the top-level standard on maintainability, serving as an application guide and which forms part of the IEC 60300-3 series of standards. It can be used to implement a maintainability programme covering the initiation, development and in-service phases of a product, which form part of the tasks described in IEC 60300-2. It also provides guidance on how the maintenance aspects of the tasks should be considered in order to achieve optimum maintainability.

## MAINTAINABILITY OF EQUIPMENT –

### Part 2: Maintainability requirements and studies during the design and development phase

#### 1 Scope

This part of IEC 60706 examines the maintainability requirements and related design and use parameter, and discusses some activities necessary to achieve the required maintainability characteristics and their relationship to planning of maintenance. It describes the general approach in reaching these objectives and shows how maintainability characteristics should be specified in a requirements document or contract.

It is not intended to be a complete guide on how to specify or to contract for maintainability. Its purpose is to define the range of considerations when maintainability characteristics are included as requirements for the development or the acquisition of an item.

The standard goes on to describe maintainability studies in the preliminary and detailed design phases and their relationships to other maintainability and maintenance support tasks, described in associated standards. Maintainability considerations in design reviews are also included.

It is intended that customers acquiring items of equipment will find this standard useful in assisting them to define their maintainability objectives and associated maintainability programmes.

#### 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 60300-3-1, *Dependability management – Part 3-1: Application guide – Analysis techniques for dependability – Guide on methodology*

IEC 60300-3-3, *Dependability management – Part 3-3: Application guide – Life cycle costing*

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

IEC 60300-3-11, *Dependability management – Part 3-11: Application guide – Reliability centred maintenance*

IEC 60300-3-12, *Dependability management – Part 3-12: Application guide – Integrated logistic support*

IEC 60300-3-14, *Dependability management – Part 3-14: Application guide – Maintenance and maintenance support*

IEC 60706-3, *Guide on maintainability of equipment – Part 3: Sections Six and Seven – Verification and collection, analysis and presentation of data*<sup>1</sup>

IEC 60706-5, *Guide on maintainability of equipment – Part 5 – Section 4: Diagnostic testing*

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

IEC 61025, *Fault tree analysis (FTA)*

IEC 61160, *Design review*

IEC 61649, *Goodness-of-fit tests, confidence intervals and lower confidence limits for Weibull distributed data*

### 3 Terms, definitions and acronyms

For the purposes of this document, the terms and definitions given in IEC 60050(191) apply, together with the following:

#### 3.1 Terms and definitions

##### 3.1.1

##### **maintainability** (performance)

ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources

NOTE The term "maintainability" is also used as a measure of maintainability performance (see 191-13-01).

[IEV 191-02-07:1990]

##### 3.1.2

##### **maintainability**

probability that a given maintenance action, for an item under given conditions of use, can be carried out within a stated time interval, when the maintenance is performed under stated conditions and using stated procedures and resources

NOTE The term "maintainability" is also used to denote the maintainability performance quantified by this probability (see 191-02-07:1990).

[IEV 191-13-01:1990]

<sup>1</sup> A second edition is due to be published shortly under the revised title "*Maintainability of equipment – Part 3: Verification and collection, analysis and presentation of data*".

**3.1.3****maintenance**

combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function

[IEV 191-07-01:1990]

**3.1.4****maintenance concept**

interrelationship between the maintenance echelons, the indenture levels and the levels of maintenance to be applied for the maintenance of an item

**3.1.5****maintenance policy**

general approach to the provision of maintenance and maintenance support based on the objectives and policies of owners, users and customers

**3.2 Acronyms**

|      |                                                  |
|------|--------------------------------------------------|
| BITE | built-in test equipment                          |
| FMEA | failure modes and effects analysis               |
| FTA  | fault tree analysis                              |
| ILS  | integrated logistic support                      |
| LCC  | life cycle cost                                  |
| LRU  | line replaceable unit                            |
| LSA  | logistic support analysis                        |
| MART | mean active repair time                          |
| MTTR | mean time to repair (or restoration or recovery) |
| RCM  | reliability centred maintenance                  |
| SSI  | software significant item                        |

**4 General approach**

An important portion of the cost of using an item is the total resources spent on those tasks necessary to retain an item in, or restore it to, a satisfactory condition. This total effort is related to the number of these tasks, their complexity and duration.

The design of an item shall ensure three things, namely:

- a) that it achieves the performance required of it;
- b) that it is reliable;
- c) that it is maintainable.

The second and third of these characteristics directly affect the maintenance effort which shall be expended on an item in that the achieved reliability reflects the frequency of unscheduled maintenance and the maintainability reflects the effort necessary to undertake all maintenance.

Therefore actions performed during the design of an item and intended to affect the failure rate and the severity of the failures call mainly for reliability techniques, while those intended to affect the preventive and corrective maintenance and the duration, cost and support requirements of maintenance tasks call mainly for maintainability techniques.

An item that can be maintained easily and is supported by a competent and efficient maintenance organization has a greater availability and a reduced life cycle cost than one that does not have these attributes. The degree of effort that is put into achieving good maintainability and an efficient support organization depends on the type of product and the use to which it is put, and is based on operational, economic and safety factors.

During the design phase, components with wear out must be identified, and their life time be determined, for example, by using Weibull analysis (see IEC 61649). The trade-off between components with higher life time versus the cost of preventive or corrective maintenance should be documented. In this way the system can be designed for minimum maintenance.

## 5 Principle of maintainability

This standard examines the maintainability and related design and use parameters and discusses some of the activities necessary to achieve the required maintainability characteristics and their relationship to the planning of maintenance.

Maintainability has a major impact on the cost of support and the availability of an equipment and is concerned with characteristics of design, manufacture and installation which affect the ability of an item to conform to specified requirements of use and of maintenance. This ability is usually measured in both qualitative and quantitative terms.

NOTE The concepts described in this standard can be applied to a small product or to a major project and therefore, as defined in IEC 60050(191):191-01-01:1990, "item" is used to denote any part, device, subsystem, functional unit, equipment or system that can be individually considered.

The maintainability characteristics depend on the following:

- a) the ability of the item to be retained in or restored to service (subject to the provision of facilities for diagnosis and accessibility of parts, etc.), all conditions of use being taken into account. The maintainability of an item is concerned with these matters but subject to the restraints of b);
- b) maintenance support, which is actually applied (personnel, training, stocks of spares, facilities, manuals, etc.). The efficiency of the maintenance support system governs the overall time to undertake the repair.

## 6 Maintainability activities in the life cycle

### 6.1 General

This standard essentially looks at the maintainability activities in the design and development phase, but there are activities during the other phases of the life cycle of an item in connection with maintainability and maintenance whose definition and achievement assist in providing the required availability and ensuring a cost-effective system. These activities are described below.

## 6.2 Concept and definition phase

### 6.2.1 General

The conditions of use and of maintenance of the item place constraints upon the maintenance concept that have to be considered during the feasibility study and the prediction of life cycle costs. The principal constraints fall into two areas, namely that of operations and resources, and the main constituents of each are given in 6.2.2 and 6.2.3.

### 6.2.2 Operational conditions

During the concept and definition phase, the following factors need to be considered:

- operating needs and performance;
- customer requirements;
- environmental conditions affecting operation and maintenance;
- means of identifying maintenance needs, particularly failure detection and localization of causes of failure (testability is described in more detail in IEC 60706-5);
- restrictions on access for maintenance purposes;
- the impact of human factors;
- equipment, software and hybrid item partitioning for maintenance purposes dictated by location, level of repair and skill classification of the maintainer.

### 6.2.3 Resources

The detailed resources are not considered at this stage, as an initial assessment needs to be made of the possible use of existing support resources, but the following factors do need to be considered:

- existing or required organization, locality, personnel and training;
- resources already committed;
- flexibility in acquiring new resources.

See IEC 60300-3-12 and IEC 60300-3-14, which give further details on the provision of resources for maintenance support.

### 6.2.4 Defining maintainability requirements

Maintainability requirements should take into account operational, reliability and safety requirements as well as cost constraints. This should result in a quantitative and qualitative maintainability specification statement considering the maintenance concept and other requirements for the item. Guidance on the maintainability clauses in specifications and contracts are given in Clause 7. Consideration should also be given during this phase to the verification of the requirements as explained in IEC 60706-3.

## 6.3 Design and development phase

### 6.3.1 Satisfying maintainability requirements

An effective means of satisfying the maintainability requirement is to carry out a maintainability programme, designed as a logical part of the whole engineering programme. Guidance for a comprehensive maintainability programme is given in IEC 60300-3-10.

### 6.3.2 Providing maintenance support planning data

Maintenance support planning shall be carried out in step with the development of an item to ensure that the maintenance support is available when the item is put into use. The main elements to be included in the maintenance support plan are as follows:

- procedures for maintaining the item (including major overhaul or software upgrades);
- the initial provisioning of spares, facilities, test equipment and tools;
- training and availability of maintenance personnel;
- technical manuals, etc.;
- testability;
- maintenance data collection system.

The plan should be consistent with the maintenance concept and needs to be updated regularly.

A system for recording the analysis and feedback of data should also be instituted. Recommended procedures are given in IEC 60706-3.

## 6.4 Manufacture and installation phase

The important maintainability activity in the phases following design and development, and leading up to the operational use of an item, is verification that the inherent maintainability designed into it has been achieved. This is a progressive activity, the extent of which depends on the nature and complexity of the item, and involves repairs and maintenance, and maintenance test tasks, carried out initially on prototype equipment, followed by early production items, to ensure that they have met their maintainability targets. Further guidance on verification and maintenance data collection is given in IEC 60706-3.

## 6.5 Operation and maintenance phases

After installation or deployment, preventive and corrective maintenance are carried out as required. The important associated maintainability activities are the collection, analysis and feedback of maintenance data. These data enable the following:

- the efficiency of the maintenance activities to be assessed;
- improvement of the design which may lead to the modification of the item;
- decisions to be made on the viability of maintenance and the possible need to renew the item, including items with pre-defined lives.

## 6.6 Disposal phase

The decision to dispose of a product is governed partly by its ability to continue to function satisfactorily, its level of reliability and maintainability and its operational cost. These factors depend on the continued provision of spare parts and support and the availability of replacement equipment.

The safe environmental disposal of an item is becoming increasingly important and may be governed by statutory regulations.

## 7 Specification of maintainability requirements

### 7.1 Statement of maintainability requirements

Maintainability should be specified in such a way that the designer has a clear understanding of the need for maintenance and the manner in which the item is to be supported. This may be reflected in a statement that defines a requirement that can be enforced in a contract. However, not all maintainability statements will be included in a contract, for example when a new product is developed in-house, maintainability requirements or goals may be based on company policy and anticipated use environment. In any case, it is essential that the objectives are clearly specified and can be verified.

**NOTE** In this standard, the term “requirement” is used to denote the stated aim of the writer and whether or not it is enforceable will be decided according to the local contractual situation.

The maintainability requirements in a specification may contain either quantitative or qualitative requirements, or both. The methods for verifying that the requirements have been satisfied should be stated, as should the existence of any constraints that might affect the maintainability characteristics of the item.

There is a progressive link between requirement, specification and contract as follows:

- the requirement is the initial statement of performance characteristics produced by a customer to which a potential supplier may submit a bid. It can also be put out from within an organization as a result of market research on a future product;
- the specification is the proposed performance characteristics of the item that are expected to respond to the requirement;
- if the specification of the proposed item is accepted, the agreed performance characteristics can be written into a contract and become the agreed requirement. The maintainability requirements are part of the overall specification and this clause details the points that may be included.

A complete statement of maintainability requirements covers the following four broad areas:

- maintainability characteristics to be achieved by the item design;
- constraints to be placed on the item deployment which will affect its maintenance;
- maintainability programme requirements to be accomplished by the supplier to assure that the delivered item has the required maintainability characteristics;
- provision of maintenance support planning.

The maintainability specification shall detail the maintainability requirements and the method to be followed to achieve them.

The specification shall be stated in terms of maintainability requirements, some of which should be specified as essential and others as desirable. The requirements should be given in measurable terms that may be either quantitative or qualitative, and they should be verifiable at later stages in accordance with prescribed procedures.

A maintainability specification typically covers requirements for the achievement of maintainability at the operational level. However, since maintainability as an item characteristic affects maintenance and support costs, and may also affect maintenance times at different maintenance levels, statements should be included in the specification covering achievements needed at all levels affected by the maintenance concept.

## 7.2 Maintainability characteristics

### 7.2.1 Quantitative maintainability characteristics

The required quantitative maintainability characteristics normally define the time that an item is in a non-operable (down) state due to being under maintenance, and it is normally a requirement that this time is kept to a minimum. There are a number of criteria that can be used to state the required characteristics related to time to undertake the repair, a selection of which are given in Table 1. The difference between them is that they express different priorities between related item properties and that they allow for flexibility concerning trade-offs to be made later in the programme. It is important that such factors are considered before a specific requirement is included in the specification. Limits may also need to be specified for the preventive maintenance tasks.

**Table 1 – Examples of quantitative maintainability characteristics**

| Term                                                                                                  | Statistical characteristic           | Verification method                                        |
|-------------------------------------------------------------------------------------------------------|--------------------------------------|------------------------------------------------------------|
| Active maintenance time                                                                               | Mean, median or maximum <sup>a</sup> | Design evaluation, demonstration or operational evaluation |
| Active corrective maintenance time                                                                    | Mean, median or maximum <sup>a</sup> | Design evaluation, demonstration or operational evaluation |
| Active preventive maintenance times                                                                   | Mean, median or maximum <sup>a</sup> | Design evaluation, demonstration or operational evaluation |
| Access time                                                                                           | Value                                | Design evaluation, operational evaluation                  |
| Number of maintenance hours per operating hour <sup>b</sup>                                           | Mean                                 | Design evaluation, operational evaluation                  |
| Number of appropriately skilled personnel per maintenance action                                      | Mean, maximum or minimum             | Design evaluation, operational evaluation                  |
| <sup>a</sup> The maximum value shall be associated with a percentile – a commonly used value is 95 %. |                                      |                                                            |
| <sup>b</sup> Other time bases may be selected as appropriate, e.g. day, month, year.                  |                                      |                                                            |

The active maintenance time is often used to specify maintainability and includes the following sub-elements:

- diagnosis (failure detection, fault detection and isolation, localization of cause, etc.);
- technical delays (typical technical delays include setting time, cooling, interpretation and application of information, interpretation of displays, read out);
- restoration (disassembly, insert software patch, interchange, modify control code, re-assembly, alignment, etc.);
- final check (testing procedures as necessary).

A variety of other maintainability characteristics may be specified for the item. Table 1 outlines some other types of characteristics associated with different classes of maintenance time and verification methods.

The maintainability of an item may also include further detailed characteristics, such as access, use of special tools and test equipment, and relationship with any existing maintenance support.

Maintainability can be used as an indirect measure of availability, using the expression for availability:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

where

MTBF is the mean time between failures;

MTTR is the mean time to repair.

Assuming that the MTBF of an item is constant, the availability is a measure of the maintainability in terms of the time to repair.

The relationship between the various elements of the overall maintenance down time is given in IEC 60300-3-10:2001, Figure 2.

### 7.2.2 Qualitative maintainability characteristics

The required qualitative maintainability characteristics include the definition of product functions, fault criteria, environmental and operational conditions and useful life of the item during which the requirements have to be fulfilled. The qualitative characteristics are related to the degree to which the item meets a specific maintenance and support policy. Where the qualitative characteristics contains numerical values, it should be qualified by a statement of the degree to which it should be met. This can be carried out by proportions of cases or events, by confidence levels or by other probabilities. Otherwise, compliance shall be judged by inspection or document review. Such policies can include statements as shown by the following examples:

- repair shall be performed by personnel of stated skill level;
- repair shall be performed by replacement of items at specified levels;
- replaceable parts shall be plug-in units;
- maintenance shall be performed according to the user's defined and established procedures;
- failed part isolation shall be performed by built-in test equipment.

There is a range of other possible qualitative subjects which may be of concern, as listed below:

- accessibility;
- maintenance skill level requirement;
- need for special tools and test equipment;
- need for adjustments;
- parts standardization;
- clear sub-system function identification;
- configuration control, fit and function;
- visual inspection access;
- built-in test equipment;
- properly marked test points;

- colour coding and labels, as appropriate;
- use of plug-in units;
- use of captive fasteners;
- use of handles on replaceable units;
- scope and range of technical manuals;
- risk of obsolescence of equipment;
- human factor limitations in the design of the item;
- safety of maintenance and operating personnel.

### 7.2.3 Testability

Testability is defined as a qualitative design characteristic which determines the degree to which an item can be tested under stated conditions. The objective of diagnostic testing is to provide cost-effective and rapid methods of fault identification in order to minimize maintenance costs and to optimize the operational use of the item. Speedy and accurate fault diagnosis is a major factor in achieving high maintainability.

The required testability characteristics may be laid down in detail in order to use existing test equipment in new products or may be left to the designer to meet general availability targets using equipment designed for the task, standard test equipment or built-in test equipment (BITE). IEC 60706-5 gives more information on testability characteristics.

### 7.3 Constraints

When writing a specification the requirements should state how maintenance should be organized and undertaken and the constraints that will be imposed on the maintainer or supplier (for example, no preventive maintenance will be allowed during certain periods of time).

The constraints needed in a specification depend on the nature of the maintainability requirements, as discussed in 7.1. It is advisable to examine this need explicitly for each objective stated. The constraints should also include any cost-limiting factors.

Generally, such constraints will include, but will not be limited to, the following:

- the need to interface with an existing or defined maintenance and support policy;
- limits for critical resources such as expensive instrumentation, high-cost spares and the number of skilled personnel at each level in the organization;
- a statement putting requirements or limits on the amount and the nature of preventive maintenance;
- environmental aspects;
- the requirement to constrain the critical resources to be held on site;
- any constraints of periods of time, relative to expected utilization of the equipment, when preventive maintenance can be carried out;
- constraints which may also be introduced by reference to other specifications, IEC publications or other publications.