BS EN 62550:2017

BSI Standards Publication

Spare parts provisioning

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee DS/1, Dependability.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2017

ISBN 978 0 580 86353 0
ICS 03.120.01; 21.020

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2017.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 62550

March 2017

ICS 03.120.01; 21.020

English Version

Spare parts provisioning (IEC 62550:2017)

Approvisionnement en pièces de rechange (IEC 62550:2017)

Ersatzteilbeschaffung (IEC 62550:2017)

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CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 62550:2017 E

European foreword

The text of document 56/1711/FDIS, future edition 1 of IEC 62550, prepared by IEC/TC 56 "Dependability" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62550:2017.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-11-24
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2020-02-24

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In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60300-1	NOTE	Harmonized as EN 60300-1.
IEC 60300-3-3:2004	NOTE	Harmonized as EN 60300-3-3:2004 (not modified).
IEC 61649	NOTE	Harmonized as EN 61649.
IEC 61709	NOTE	Harmonized as EN 61709.
IEC 62308	NOTE	Harmonized as EN 62308.
IEC 62402	NOTE	Harmonized as EN 62402.
IEC 62506	NOTE	Harmonized as EN 62506.

IEC 62550

Edition 1.0 2017-01

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Spare parts provisioning

Approvisionnement en pièces de rechange

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 03.120.01; 21.020

ISBN 978-2-8322-3834-9

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SPARE PARTS PROVISIONING

FOREWORD

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International Standard IEC 62550 has been prepared by IEC technical committee 56: Dependability.

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

FDIS	Report on voting
56/1711/FDIS	56/1719/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 the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

INTRODUCTION

Spare parts provisioning is the process for planning necessary spare parts under consideration of a customer's needs and requirements.

Proper planning and control of spare parts is a critical component of effective supportability. If the right parts are not available when needed for routine maintenance or repairs, downtime is prolonged. If too many spare parts are available, the enterprise absorbs excessive costs and the overhead of carrying inventory.

Spare part planning and supply to achieve business objectives are based on four goals:

- the right spare part;
- in the right quantity;
- at the right time;
- at the right place.

Spare parts provisioning is a prerequisite for all types of maintenance tasks, such as replacements and repairs. Spare parts for corrective maintenance tasks should be supplied at random intervals for steady state availability. It may take three to four repairs before steady state availability is reached. In this period repairs may be clustered, and the need can vary significantly over time. For preventive and on-condition maintenance, fixed intervals or approximately fixed intervals for replacement items may occur. Coordination of demand for spare parts with supply of spare parts at the required time is an important factor. Unavailable materials are one of the most cited reasons for delays in the completion of maintenance tasks.

The availability of spare parts is one of the factors that impacts system downtime. Methodologies such as integrated logistic support (ILS) and its subsidiary logistic support analysis (LSA) provide necessary information for spare parts provisioning. This information includes system breakdown, maintenance concept, and supply concept. Spare part optimization will cover issues typically giving answers to questions such as:

- which spare parts should be stored within the maintenance organization or by a supplier?
- how many spare parts of each type should be stocked?

Spare part optimization is based on operations research methods and selected reliability methods and may be analytical or use Monte Carlo simulations. The optimization process aims at balancing the cost of holding spare parts against the probability and cost of spare part shortage.

Before spare parts can be ordered, procedures for procurement, administration and storage of required material should be specified. Additionally, a general supply concept should be compiled and specified.

Correct material supply procedures will guarantee that spare parts are ordered in time and delivered when requested. The procedures also include control of the repair of replacement parts as well as the monitoring of repair turn-around times. All organizations involved, from production to purchasing and storage, via maintenance, should have complete transparency about material availability and possible completion of the task. The planned material costs in the task should be compared with its consumption. These are then documented and form the basis of usage-controlled materials planning. With this process, inventory of spare parts can be optimized to meet availability requirements with minimum inventory levels.

This document is applicable to all industries where supportability has a major impact on the dependability of the item through its life cycle.

SPARE PARTS PROVISIONING

1 Scope

This document describes requirements for spare parts provisioning as a part of supportability activities that affect dependability performance so that continuity of operation of products, equipment and systems for their intended application can be sustained.

This document is intended for use by a wide range of suppliers, maintenance support organizations and users and can be applied to all items.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

NOTE Some terms listed in IEC 60050-192 are also included here for the convenience of the reader.

3.1 Terms and definitions

3.1.1
consumables
any item which is expendable, may be regularly replaced and generally is not product specific

EXAMPLE Oil, grease, nuts, bolts and screws, gaskets, etc.

Note 1 to entry: Generally consumable items are relatively low cost.

3.1.2
corrective maintenance
maintenance carried out after fault detection to effect restoration

Note 1 to entry: Corrective maintenance of software invariably involves some modification.

[SOURCE: IEC 60050-192:2015, 192-06-06]

3.1.3
failure
<of an item> loss of ability to perform as required

Note 1 to entry: A failure of an item is an event that results in a fault state of that item: see fault [IEC 60050-192:2015, 192-04-01].

Note 2 to entry: Qualifiers, such as catastrophic, critical, major, minor, marginal and insignificant, may be used to categorize failures according to the severity of consequences, the choice and definitions of severity criteria depending upon the field of application.

Note 3 to entry: Qualifiers, such as misuse, mishandling and weakness, may be used to categorize failures according to the cause of failure.

[SOURCE: IEC 60050-192:2015, 192-03-01]

3.1.4
indenture level
level of sub-division within a system hierarchy

EXAMPLE System, subsystem, assembly, and component.

Note 1 to entry: From the maintenance perspective, the indenture level depends upon various factors, including the complexity of the item's construction, the accessibility of sub items, skill level of maintenance personnel, test equipment facilities, and safety considerations.

[SOURCE: IEC 60050-192:2015, 192-01-05]

3.1.5
integrated logistic support
ILS
<of an item> management process to determine and co-ordinate the provision of all materials and resources required to meet the needs for operation and maintenance

[SOURCE: IEC 60050-192:2015, 192-01-30]

3.1.6
item
subject being considered

Note 1 to entry: The item may be an individual part, component, device, functional unit, equipment, subsystem, or system.

Note 2 to entry: The item may consist of hardware, software, people or any combination thereof.

[SOURCE: IEC 60050-192:2015, 192-01-01, modified — omission of internal references and Notes 3, 4 and 5]

3.1.7
level of maintenance
maintenance level
set of maintenance actions to be carried out at a specified indenture level

[SOURCE: IEC 60050-192:2015, 192-06-04]

3.1.8
line replaceable item
LRI
replaceable hardware or software unit which can be replaced directly on the equipment by the user or by a maintenance support facility

Note 1 to entry: In some projects instead of LRI the term line replaceable unit (LRU) is applied.

3.1.9
maintenance
combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required

Note 1 to entry: Management is assumed to include supervision activities.

[SOURCE: IEC 60050-192:2015, 192-06-01]

3.1.10
maintenance policy
maintenance concept
definition of the maintenance objectives, line of maintenance, indenture levels, maintenance levels, maintenance support, and their interrelationships

Note 1 to entry: The maintenance policy provides the basis for maintenance planning, determining supportability requirements, and developing logistic support.

[SOURCE: IEC 60050-192:2015, 192-06-02]

3.1.11
line of maintenance
maintenance echelon
position in an organization where specified levels of maintenance are to be carried out

EXAMPLE 1st line – field; 2nd line – repair shop; and 3rd line – manufacturer's facility.

Note 1 to entry: The line of maintenance is characterized by the level of skill of the personnel, the facilities available, the location, etc.

[SOURCE: IEC 60050-192:2015, 192-06-03]

3.1.12
maintenance support
provision of resources to maintain an item

Note 1 to entry: Resources include human resources, support equipment, materials and spare parts, maintenance facilities, documentation and information, and maintenance information systems.

[SOURCE: IEC 60050-192:2015, 192-01-28]

3.1.13
maintenance action
maintenance task
sequence of elementary maintenance activities

EXAMPLE Fault localization, fault diagnosis, repair and function checkout.

[SOURCE: IEC 60050-192:2015, 192-06-11]

3.1.14
non-repairable item
item that cannot, under given conditions, after a failure, be returned to a state in which it can perform as required

Note 1 to entry: The “given conditions” may include technical, economic and other considerations.

Note 2 to entry: An item that is non-repairable under some conditions may be repairable under other conditions.

[SOURCE: IEC 60050-192:2015, 192-01-12]

3.1.15
obsolescence
transition from availability from the original manufacturer to unavailability or a permanent transition from operability to non-functionality due to external reasons

3.1.16
preventive maintenance
preventative maintenance
maintenance carried out to mitigate degradation and reduce the probability of failure

[SOURCE: IEC 60050-192:2015, 192-06-05, modified — deletion of Note1 to entry]

3.1.17
repairable item
item that can, under given conditions, after a failure, be returned to a state in which it can perform as required

Note 1 to entry: The “given conditions” may include technical, economic and other considerations.

Note 2 to entry: An item that is repairable under some conditions may be non-repairable under other conditions.

[SOURCE: IEC 60050-192:2015, 192-01-11]

3.1.18
spare part
component or part, either non-repairable or repairable, from the associated bill of material used to maintain or repair machinery or equipment

3.1.19
stock position
any location where a spare part is foreseen to be inventoried

Note 1 to entry: The terms stock and inventory are generally interchangeable.

3.1.20
supportability
<of an item> ability to be supported to sustain the required availability with a defined operational profile and given logistic and maintenance resources

Note 1 to entry: Supportability of an item results from the inherent maintainability, combined with factors external to the item that affect the relative ease of providing the required maintenance and logistic support.

[SOURCE: IEC 60050-192:2015, 192-01-31, modified — omission of internal reference]

3.1.21
system
<in dependability> set of interrelated items that collectively fulfil a requirement

Note 1 to entry: A system is considered to have a defined real or abstract boundary.

Note 2 to entry: External resources (from outside the system boundary) may be required for the system to operate.

Note 3 to entry: A system structure may be hierarchical, e.g. system, subsystem, component, etc.

Note 4 to entry: Conditions of use and maintenance should be expressed or implied within the requirement.

[SOURCE: IEC 60050-192:2015, 192-01-03]

3.2 Abbreviated terms

BOM	Bill of material
CS	Communication system
DCN	Data communication network
DTN	Data transport network
EBO	Expected backorders
FR	Fill rate
ILS	Integrated logistic support
IP	Initial provisioning

IPC	Illustrated parts catalogue
IPD	Initial provisioning data
LORA	Level of repair analysis
LRI/LRU	Line replaceable item/Line replaceable unit
MAD	Mean administrative delay
MoE	Measures of effectiveness
MDT	Mean down time
MLD	Mean logistic delay
MRT	Mean repair time
MTBF	Mean operating time between failures
MTBR	Mean time between replacements
MTD	Mean technical delay
MTTF	Mean time to failure
MTTR	Mean time to restoration
MWT	Mean waiting time
NFF	No fault found
NI	Not illustrated
NOR	Not operationally ready
OEM	Original equipment manufacturer
QPNHA	Quantity per next higher assembly
ROS	Risk of shortage
TAT	Turn-around time
TT	Transportation time

4 Overview

4.1 Participants and major steps in the spare parts provisioning process

Items, which are foreseen to be replaced during maintenance actions are defined as spare parts. The storage of spare parts is part of a comprehensive material provisioning process which ensures that the required spare parts for maintenance are provided in the necessary quantity, at the appropriate point in time and in the right place.

This document is applicable to items, which include all types of products, equipment and systems (hardware and associated software). Most of these require a certain level of maintenance to ensure that their required functionality, dependability, capability, and economic, safety and regulatory requirements are achieved.

The availability of a supported system is influenced by the overall effectiveness of maintenance. Thus, the availability of a system can be regarded as the general objective for spare parts provisioning. The potential impact of obsolescence should also be considered as an influencing factor (see IEC 62402).

The operator of an item has to offer a high level of service and performance. The maintenance organization is responsible for the effectiveness, elapsed time, and cost of the maintenance activities. An overview of specific responsibilities and targets as well as the major steps in the spare parts provisioning process are shown in Figure 1.

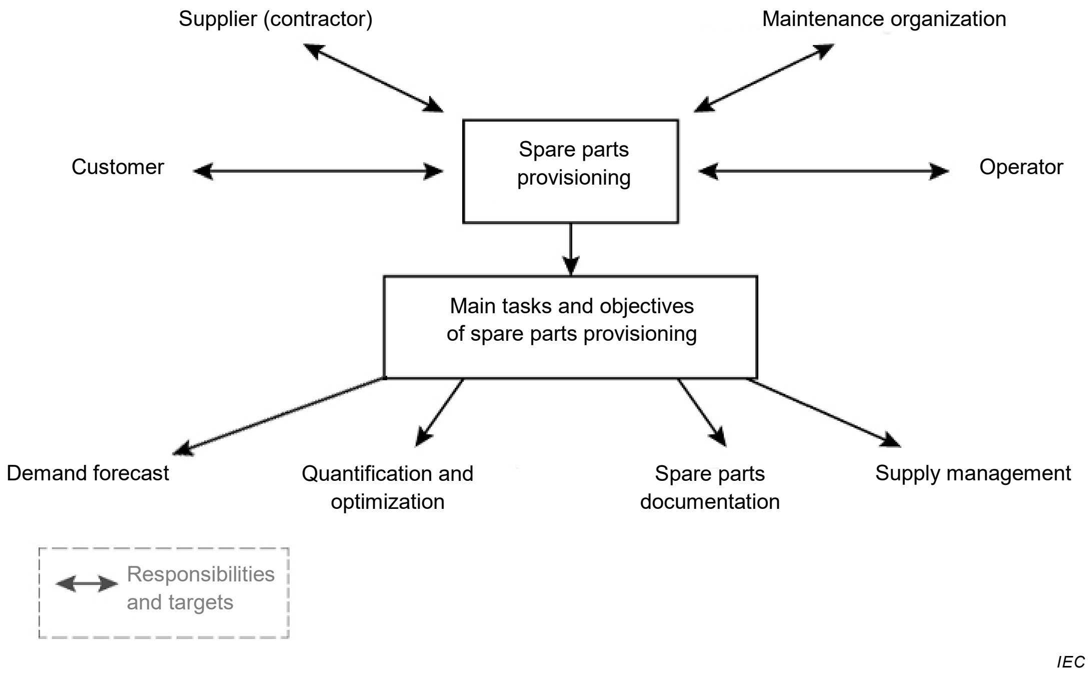


Figure 1 – Participants and major steps in the spare parts provisioning process

For satisfying the demand of spare parts, the following considerations have to be made:

- which spare parts are required;
- how many spare parts should be stocked;
- where should the spare parts be stored;
- when should the spare parts be ordered or reordered;
- what is the most economical solution for all participants.

In Table 1, responsibilities, targets and measurements for the different participants are shown as an example.

Table 1 – Responsibilities, targets, and measurements for suppliers, maintainers, operator and users

	Supplier of spare parts	Maintenance organization	Operator/user
Responsibility	appropriate spare parts availability quality of delivered items quality of supply service	high availability of maintained items high maintenance service	high operational availability
Target	profit with supply of spare parts certification of items (if required)	ensure that the system is successfully restored profit of the maintenance organization	operator: operational profit and availability user: high service performance
Measurements	service level lead time	system down times maintenance cost repair quality	system availability quality of service

4.2 Types of spare parts

For most maintenance tasks, materials and spare parts are required. When a component fails, it is replaced by a new or repaired component. The time of the replacement depends on the maintenance concept. If the failed item is repairable, it can be repaired off-line or in situ. The repair-by-replacement policy requires that new or ready-for-use spare parts are quickly available at the moment that failures occur.

During maintenance, some materials, referred to as consumables, are consumed or replaced and are not able to be re-used. Other items are called spare parts and are distinguished as

- repairable items, or
- non-repairable items.

Ideally, repairable items can be repaired in each case. In some instances, such as when the repair is not economic or not technically possible, or where the reliability of the item has been degraded by the number of repair actions undertaken, they are condemned and replaced by a new item.

In many projects, especially for large systems, repairable items can represent a significant proportion of the initial investment in spare parts. With regard to products such as household equipment, entertainment equipment or even cars, repairable items represent a smaller portion.

Non-repairable items are ones that are not able to be repaired due to technical factors or are not worthwhile to be repaired due to economical reasons. They are then condemned and replaced by a new item. The quantity of non-repairable items is determined similarly to the repairable items by the demand rate and the time until a new part is made available. This time comprises the procurement lead time, administrative delay times, and transport times.

Non-repairable items are consumed during maintenance. The initial investment in those items compared to repairable items is small, but the yearly cost for replenishment may be considerable.

In addition to repairable and non-repairable items, consumables have to be provided, such as nuts, bolts, washers, lubricants. When applicable, consumables are mentioned, but it is not the intention of this document to address consumables in detail.

4.3 Identification of spare parts as integral part of the level of repair analysis (LORA)

LORA is a specific trade-off study that is used to identify the optimum maintenance level or location for a repair to be undertaken. LORA will also identify the lowest repairable item such as a bearing or motor, or a complete motor generator, which relates to the combination of spares cost plus labour cost times task frequency versus opportunity costs that provides the best return on investment for the organization. It may be used for design optimization or as part of a support system assessment.

During the design stages, LORA addresses a number of scenarios, which may include the following:

a) The maintenance methodology, such as to:
   - replace and dispose;
   - repair in situ;
   - replace and repair externally.
b) The indenture level for removal such as to:
   - remove the item as part of a sub-assembly, and replace and repair at the current maintenance echelon level;

- remove the item as part of a sub-assembly, and replace and repair at a higher maintenance echelon level;
- remove and replace the item with repair at the current echelon level;
- remove and replace the item with repair at a higher echelon level.

c) The echelon, such as:
- during operational use;
- in the field with the system non-operational;
- at a repair shop (may be multi-echelon);
- at the manufacturer’s site.

LORA also has to operate within a number of constraints such as:

- the maintenance concept which may pre-determine the maintenance echelons and their capability of repair;
- criticality of the items;
- user policy and constraints;
- safety criteria;
- proprietary aspects;
- customer requirements;
- economic aspects.

The types of spare parts that are needed are defined during the development of the maintenance concept and it is part of the LORA process and/or the establishment of the required supportability.

The principles of spare parts identification are illustrated in Figure 2.

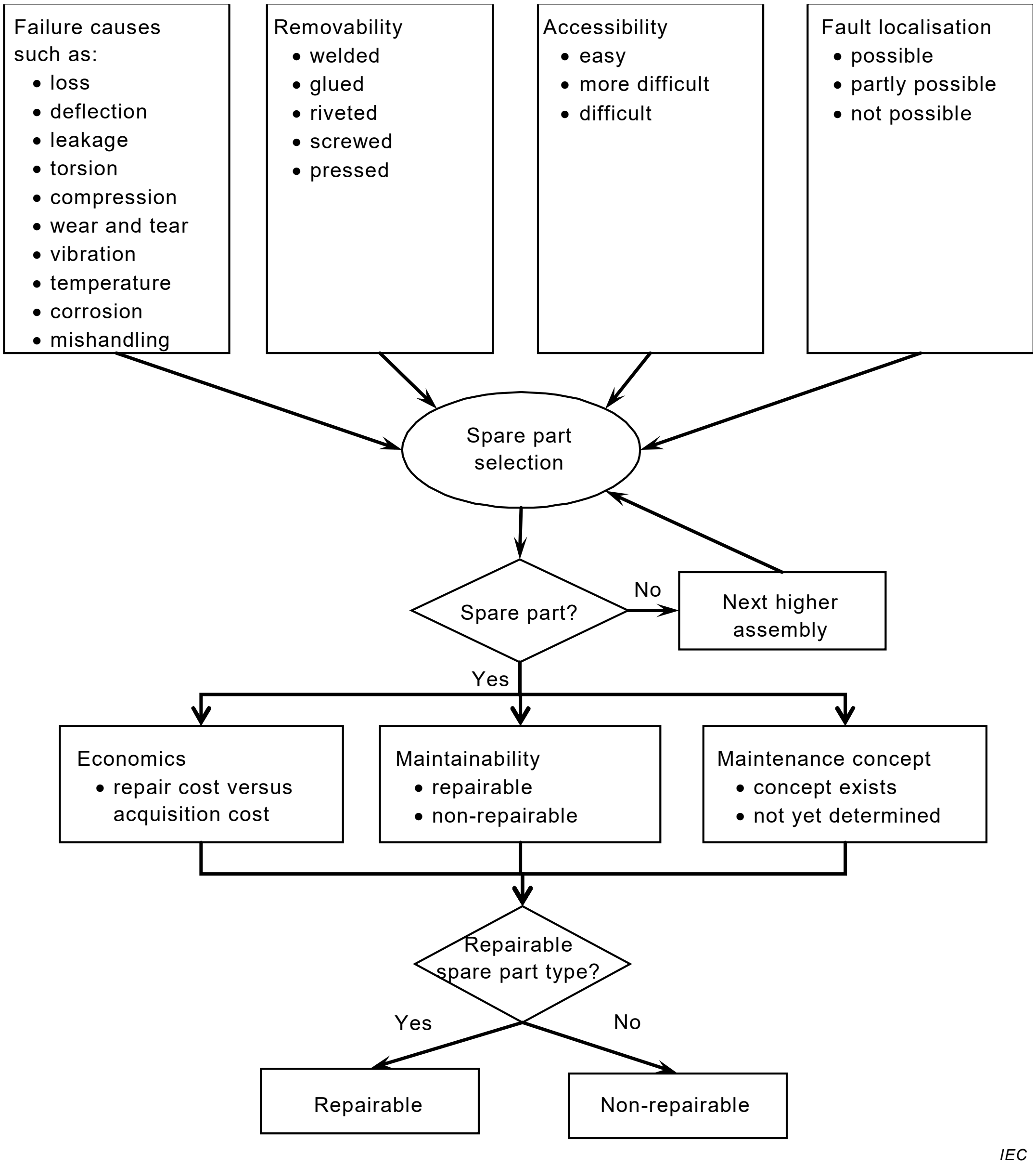


Figure 2 – Identification of spare parts

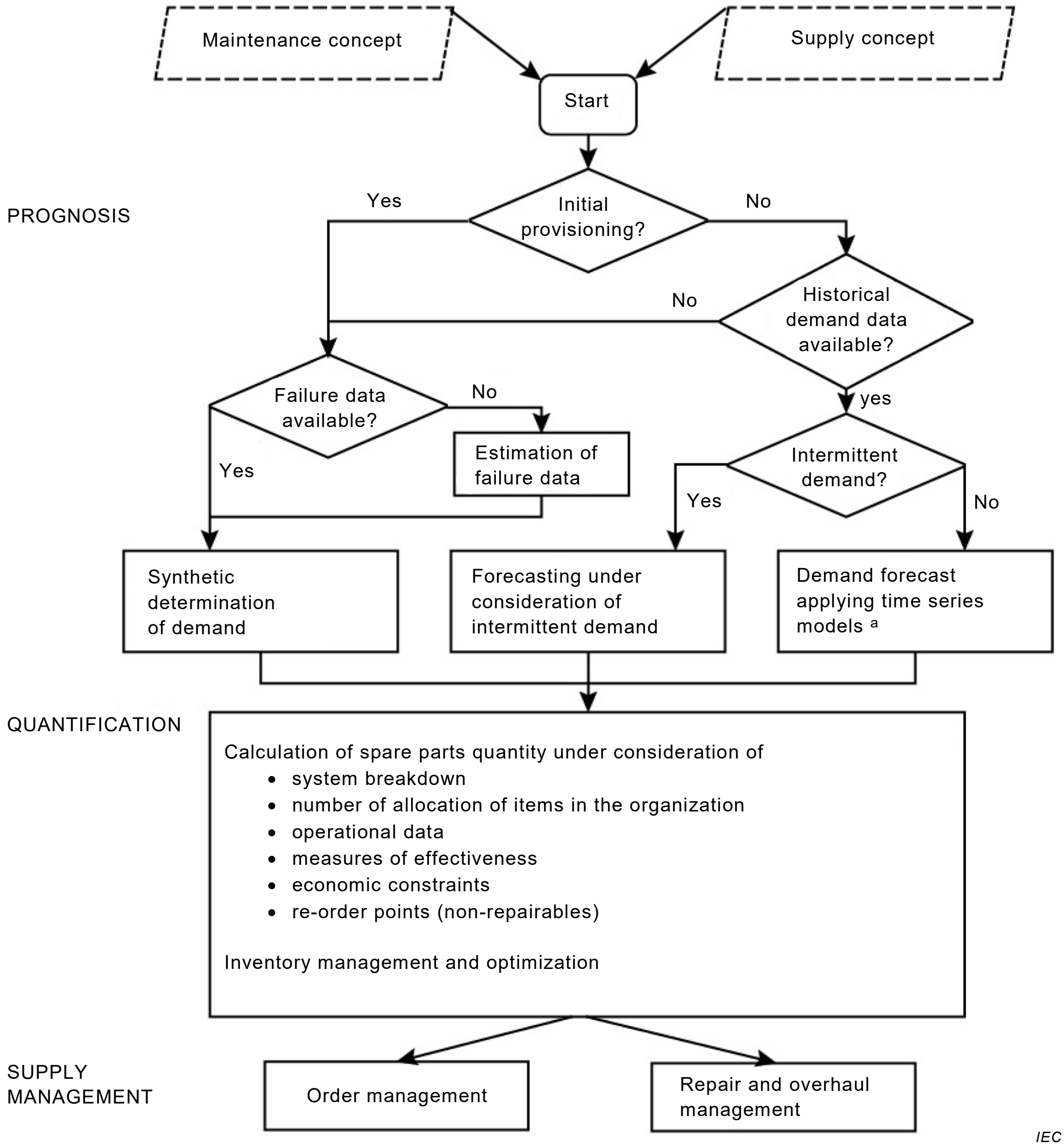
All spare parts, consumable items, special supplies and related inventories needed to support corrective and preventive maintenance tasks are elements of supportability. The quantity of spare parts to be supplied and stocked should be determined for each maintenance echelon (see Clause 6).

The vast majority of spare part (and consumable) quantities for scheduled preventive tasks may be derived deterministically as the requirements for each task are known in advance. However, some tasks, which include a condition monitoring element will require parts to replace items identified as failed or failing. Such parts may be required as part of the task which identified the need or later as part of a scheduled corrective task. In either case, the quantification of spare parts required can be performed in the same manner as that for any corrective task.

4.4 Overall spare parts provisioning process

The overall spare parts provisioning process can start when the maintenance concept has been elaborated as described in the previous subclause and when a supply concept is available. Both the maintenance and supply concept may be adjusted during the spare parts provisioning process.

In Figure 3, the major steps in the spare parts provisioning process are shown.



Key

[a] For example: exponential smoothing.

Figure 3 – Spare parts provisioning process during design and development

5 Demand forecast

5.1 General

The demand for spare parts determines the size and organization of the inventory system. The accuracy of the demand forecast is a decisive factor for the quality of the disposition model. The demand is expressed by the required quantity of an item during a specified period of time.

If the level of the future demand is known and can be determined, it is regarded as deterministic, otherwise it is stochastic. A demand or the distribution of demand, which is variable over time, is regarded as a dynamic process. When there is no influence of time on the demand, the process is regarded as stationary. A relatively even structure of demand will result in a continuous spare parts requirement; fluctuating demand is regarded as sporadic. For spare parts, all described demand characteristics are applicable. A generally preferred method of demand forecast is not available.

For technical systems or facilities, a demand occurs when an item fails and has to be replaced by a functional item. The demand is determined by the intensity of use, the failure behaviour of the item and environmental aspects. Ideally, quantified values for applicable parameters are able to be determined within this context. Determination of the failure rate is achieved via investigation of the behaviour of a representative number of identical items or items of similar design by applying statistical methods, for example, Weibull analysis (IEC 61649). The prognosis method actually used for demand forecast will depend on the actual information available. If the failure rate and/or intensity of use are missing as concrete figures, only prognosis methods can be applied by substituting the missing information using assumptions with an associated higher risk.

5.2 Forecast based on consumption data

5.2.1 General

A production process can generally be regarded as a deterministic process since material planning is conducted by the production process and interrelated inventory. Buffer stocks have to be put in place only for short-term and medium-term deviations in the production. Major changes in the production demand will cause a change in production capacity. The requirements at spares stocks are mostly of a stochastic nature, i.e. only over a longer period or over a larger number of operational systems can the need be planned on the basis of average values. The deviations from these average values are often considerable.

The intermittent nature of spare part demand due to failures makes it difficult to apply conventional time series based algorithms. The choice of the right model becomes essential and that would depend on usage rates and operational patterns.

5.2.2 Procedures for forecast

The overview of existing forecast procedures described in detail in Annex A cannot only be applied for the forecast of spare parts but also in general for the demand forecast in industry and trade.

Procedures for demand forecast can be divided into three major categories:

- deterministic procedures;
- statistical analysis;
- subjective estimation.

For a number of items it can be too complex to perform demand planning from the provided BOM of the semi-manufactured and/or final products. In these cases, past consumption can be assumed as an indicator for future material consumption. The factors that determine the materials consumption are then not considered and it is assumed that the influencing variables which worked in the past will affect future material consumption in the future in an analogous way. Past consumption is thus considered as the basis for demand planning. From so-called time series, conclusions as to future demand may be drawn.

5.3 Initial determination of demand

5.3.1 General

In the previous paragraph it was explained that, if historical data for a unit is available, the demand rate can be forecasted. At the initial stages, often no historical data is available for an estimation of the amount of maintenance and logistic support including spare parts. Consequently, methodologies for reliability prediction are required for early use during system development. Such methodologies exist (especially concerning electronic equipment). It should be noted that these methods are based on empirical data. This means that formulas and data are based on existing technology, design practice and equipment environment.

The following characteristics affect reliability significantly:

- system design;
- component quality;
- stress intensity;
- environmental factors.

For more detailed information, there are specific standards or reliability data handbooks for specific industries available (see IEC 61709).

Consideration could also be given to:

- supplier requirements on maintenance methods and frequencies, as well as supplier exchange frequencies for wear-out parts related to supplier guarantees;
- specific insurance requirements;
- spare parts for systems/components with long life, long usage period when technical development, or other factors (e.g. supplier out of business) affect the availability of spare parts;
- aging of spare parts/consumables in storage and requirements of correct storage – packaging, environmental characteristics such as humidity and temperature (see IEC PAS 62435).

5.3.2 Prediction of failure rates and failure intensities

The failure rate and intensity of an item are essential parameters when determining the number of spares required. According to their definitions, failure rate is for non-repairable items and failure intensity is used for repairable items. For this document, since it is not always possible to determine which one is applicable, failure rate is used for both repairable and non-repairable items because in both cases an action needs to be taken to deal with the failure, i.e. either a permanent replacement or a repair. The accuracy of the failure rate value is a risk factor that should be considered when estimating the quantity of spares. The failure rate can be obtained from published data, historical data, testing, and operational usage. Commercial organizations publish 'average' values for component failure rates and environmental factors based upon data received from a wide range of industries. Historical data by a company for an item (or similar items) can produce more accurate failure rates if there is sufficient data available for the items operating in the specified or comparable environment. Testing a system to establish accurate failure rates can be prohibitively expensive and usually only serves to give confidence in the derived values. Operational usage can provide the best data, but this is not available for initial spares. However, gathering this data can enable the failure rates to be adjusted for future spares provisioning (see also IEC 61709).

When calculating the number of spares, it is usually assumed that the failure rate does not change over time (or number of cycles, distance travelled, etc.). This constant failure rate may not be correct, but when a large number of components is used in the product (system), each having failures that occur stochastically over time, the product (system) tends to a constant failure rate. It is important to recognize that a risk factor exists for initial spares provisioning when using a constant failure rate if small quantities are in operation; even for large quantities, it may take a year or more before the failures are sufficiently random over time for an item's failure rate to become constant.

The failure performance is specified either by the failure rate or by the MTBF. For a constant failure rate, the MTBF is the reciprocal term of the failure rate.

When the failure rate is not constant, it may be caused by a wear-out failure mechanism and variance in the life distribution. In such cases, life prediction should be performed and reflected in the failure rate prediction for the required time interval.

5.3.3 Calculation of demand rates

In the synthetic procedure, the demand rate λ is calculated on the basis of the estimated failure rate and the number of identical items under analysis. Applicable equations are shown in Clause A.3.

The expression $\lambda\, T$ represents the average number of demands during a given time T. It can be calculated by Formula (B.3) in Annex B.

Sometimes faults are indicated, which are unconfirmed during a later test. Therefore, the probability of no fault found (NFF) has to be included in the calculation of the demand rate. Some failures (secondary failures) are induced by external events, such as inappropriate repair, failure of other items. For these reasons the replacement rate and not the failure rate has to be applied in spare parts quantification. The replacement rate includes all external factors, which are influencing the number of removals of an item (see Annex B).

6 Spare parts quantification

6.1 General

6.1.1 Process overview

The methods used to manage spare parts provisioning depend on their use for preventive or corrective maintenance.

For corrective maintenance, the spare parts quantification and optimization should initially be performed on the basis of MTBF, MTTF or non-constant failure rates applying mathematical and statistical methods. The accuracy of the quantification has a significant impact on both the cost and the availability of the product. MTBF, MTTF or failure rates are initially estimated but, with the experience of use, a better correlation is established from actual usage data. In addition to reliability parameters, the required quantity of non-repairable items is determined based on the period for which spares have to be provided and should be optimized. For the quantification of repairable items, the repair turn-around time needs to be considered.

For preventive maintenance, the quantification of spare parts is mainly deterministic, and in some cases, the quantity of spare parts is derived from a probabilistic pattern.

Complex technical systems consist of many items. These items again may be made up of assemblies, sub-assemblies and/or components. If a failure arises in such a system, it depends to a large extent on the effectiveness of the fault diagnosis and isolation as well as on the repair effort, how quickly the system can be repaired and when the system is ready again. Another important factor in this context is the availability of spare parts. High system availability requires a sufficient supply of spare parts and is particularly crucial if the repair times of assemblies or individual parts are long, and the replacement times at the system level are short.

Spare part stocks require considerable investment. The increasing shortage of funds and/or the growing pressure of competition require methods of spare parts quantification which consider both technical and economic boundary conditions.

The cost of repairable items represents a major part of the total cost of spare parts. However, their number is relatively small. The required quantity is basically determined by the repair turn-around time and the failure frequency. The selection and quantification of repairable parts require great care.

The required quantity of non-repairable items is determined, apart from the failure frequency, substantially by the re-provisioning time, which includes lead time and processing time. Procedures for the quantification of non-repairable items are therefore different from those for repairable items.

The overall spare parts provisioning process during design and development is shown in Figure 4.

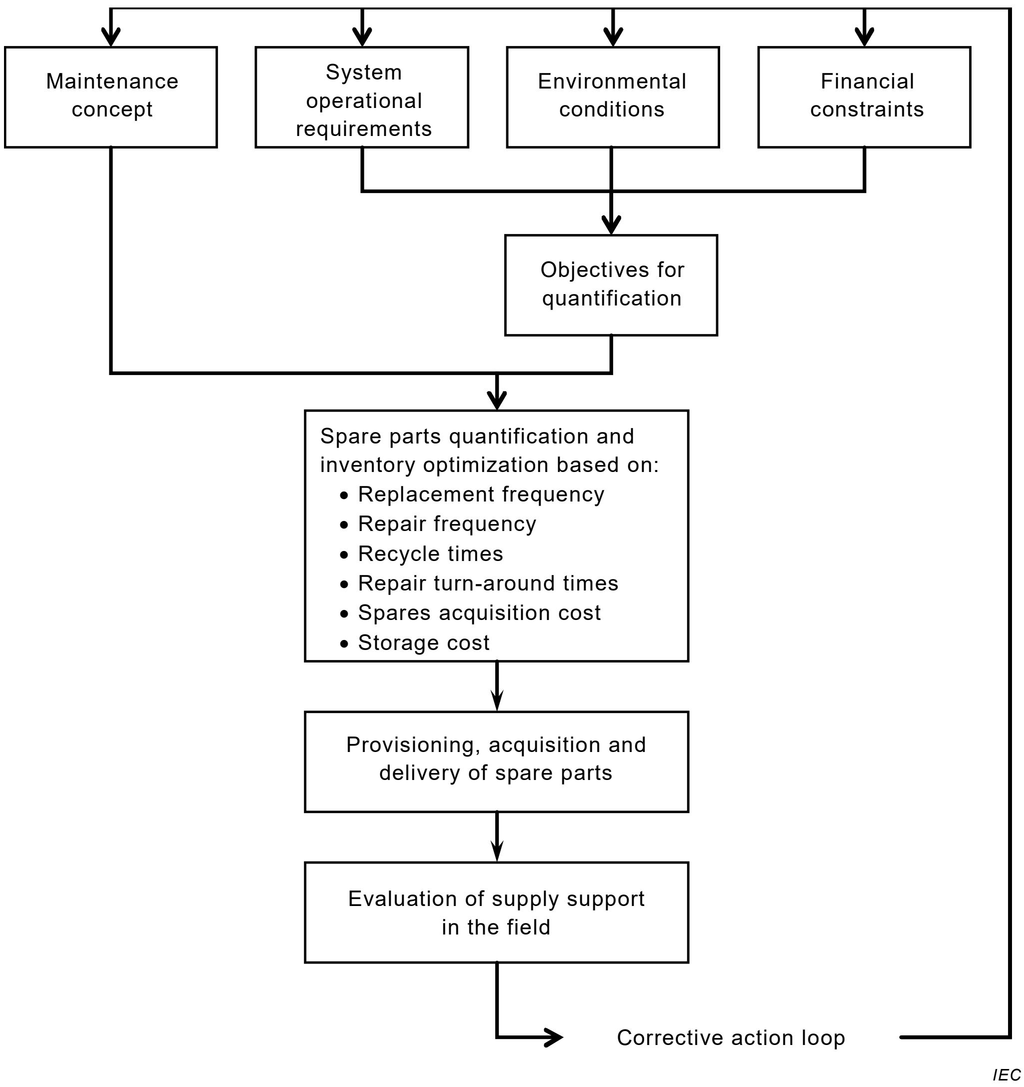


Figure 4 – Spare parts provisioning process during utilization

Spare parts quantities are based on the following:

- spare parts required for corrective maintenance (repairable items and non-repairable items);

- spare parts required for preventive maintenance (items which are replaced periodically);
- spare parts required to replenish the stocks of non-repairable items;
- spare parts necessary to support operation while repairable items are being repaired (turn-around times);
- spare parts required to replace repairable items which are condemned (condemned items are removed from the inventory).

Spare parts may be sourced directly from a vendor or manufacturer or may be stored in readiness for use to guarantee their availability. It is important to ensure that they are appropriate for their intended use.

6.1.2 Probability distributions for spare parts quantification

Spare parts quantification is performed on the basis of probability distributions. Selection of the applicable distribution depends on failure characteristics. The following probability distributions can be used for spare parts quantification with the Poisson distribution being the most common:

- the Poisson distribution with all simple computing procedures, for example, in spread-sheet programs, if the value (λT) is smaller than 50; between $50 \leq \lambda T \leq 100$, both the Poisson and the normal distribution can be used;
- the normal distribution at values (λT) greater than 100;
- the negative binomial distribution for compound problems, for example, multi-echelon or multi-indenture applications, may be applied if readily available, otherwise the Poisson distribution can be used without large loss of accuracy;
- the log-normal distribution, for example, for cases such as estimating the number of products in the filed (population at risk);
- other probability distributions only in justified cases, for example, the Weibull distribution is used for analysis of components with limited life (wear out).

The Poisson distribution is a single-parameter distribution where the expected value and the variance have the same value. The Poisson distribution can be applied when some measure (time or something else) is continuous while the number of events which may occur during this continuous random variable is established by counting (discrete). It can be applied when the probability of occurrence is very small. This is the case when the time interval is long and/or the demand rate is low. The Poisson distribution is the most commonly applied probability distribution for the quantification of spare parts.

The normal distribution is a two-parameter distribution and is applicable when the distribution of a random variable is determined by many factors independent from each other. The normal distribution is applied when a high demand rate occurs. The normal distribution is therefore frequently used with high consumption rates for the determination of the safety stock of non-repairable items. Since the normal distribution could result in negative values, care should be taken to avoid this.

The Poisson distribution can be regarded as a particular type of the negative binomial distribution. The negative binomial distribution is sometimes used for a multi-indenture and multi-echelon inventory system. For the negative binomial distribution, both time (or other related variable) and the random variable are counted (discrete), for example the number of failed items up until finding a working one.

When performing spare parts quantification, a constant failure rate over time is presumed. For large populations, the observed rate appears constant because the varying operating time intervals result in failures becoming evenly distributed. Applying the Weibull type distribution or negative binomial distribution requires two parameters with sufficient statistical confidence.

6.1.3 Measures of effectiveness (MoE)

6.1.3.1 Overview

High effectiveness of supportability is crucial for the availability and the economical operation of a system. Therefore optimization of maintenance policies, maintenance resources, and spare parts inventory policies should be conducted in parallel.

MoE for spare part management can be divided into two groups:

- stock-related MoE, such as fill rate, risk of shortage, expected backorders, mean waiting time;
- system-related MoE, such as operational system availability, number of systems NOR, probability of mission success.

The cost optimization of an inventory system is attained by a trade-off of these measures of effectiveness against inventory cost.

6.1.3.2 Fill rate (FR)

This MoE is defined as the probability that demand can be satisfied immediately. It is calculated per stock position. FR is sometimes also referred to as service level or demand satisfaction rate.

The average FR is calculated as a weighted average for groups of stock positions according to the relative demand rate of each stock position. The relative demand rate is in this context based either on the entire demand rate to the stock position or on the demand rate with a certain origin.

6.1.3.3 Risk of shortage (ROS)

This MoE is defined as the probability of an unsatisfied (backordered) demand. It is calculated per stock position, with the same definitions and assumptions as described in 6.1.3.2 for FR.

The ROS is the complement to the FR and is calculated as 1-*FR*.

The measure ROS does not state anything about the time delay, which results from the lack of spare parts. Therefore, the mean waiting time is a meaningful measure.

6.1.3.4 Expected backorders (EBO)

An additional MoE when performing spare parts quantification is the average number of backorders (EBO). The backorder is a measure of those demands, which are not fulfilled immediately but postponed until the next supply (for repairable items the next return of a repaired item). Both the number and the measure of the temporary delay are considered in this measurement.

6.1.3.5 Mean waiting time (MWT)

The waiting time at a stock position is the time from when a demand – an order – occurs until the requested item can be handed out from stock. If the item is on hand at the moment when a demand occurs then the waiting time is zero. Delays in delivery due to administrative procedures or physical handling of the item are considered to be part of the administrative delay time and the transportation time.

The MWT is a weighted average, according to the relative demand rate of each stock position. The waiting time is a part of the technical delay and sometimes MWT can be equal to MTD.

It is assumed that as soon as a unit arrives at a stock position, it is available to be handed out. Hence, any time spent on unpacking the item is thus considered to be part of the administrative delay time.

Note that the above definition is used even when the nominal (maximum) number in stock is zero. The waiting time is then equal to the waiting time at the supporting stock position plus the transportation time and repair turn-around time.

MWT plays an important role with quantification and optimization of multi-indenture and multi-echelon inventory systems.

6.1.3.6 Operational system availability

The time fraction of a system's availability during the entire period of operation is defined as the operational system availability.

6.1.3.7 Number of systems not operationally ready (NOR)

The expected NOR is calculated for all groups of systems where availability is calculated. This MoE gives the mean NOR in the group that are unavailable due to down time.

6.1.4 ABC-analysis (Pareto analysis)

Inventory frequently contains a great number of different spare parts, especially non-repairable items. Such a range of items is believed to be a barrier to perform a detailed inventory analysis. The cost for the assessment of thousands of items having a generally low individual price outweighs the stock value. For practical reasons, not all items can be planned and controlled with the same effort. This results in the requirement for a procedure that relates the costs for planning and control of individual items with their contribution to the overall investment. ABC analysis does not consider the criticality of spares for operation or safety, nor does it consider the delivery time.

Storage cost and system unavailable cost could also be included as a contribution to the overall investment if it is considered to be significant.

ABC-analysis enables a procedure for classifying a range of spare parts by grouping the individual articles into three classes. The procedure includes the following steps:

- calculation of an annual budget for each individual article based on consideration of the item's price and its annual demand;
- ranking of all articles by descending order of the annual budget;
- calculation of the percentage of each article's impact on the total budget;
- accumulation of the percentages;
- categorization into A-, B-, and C-articles (see Figure 5).

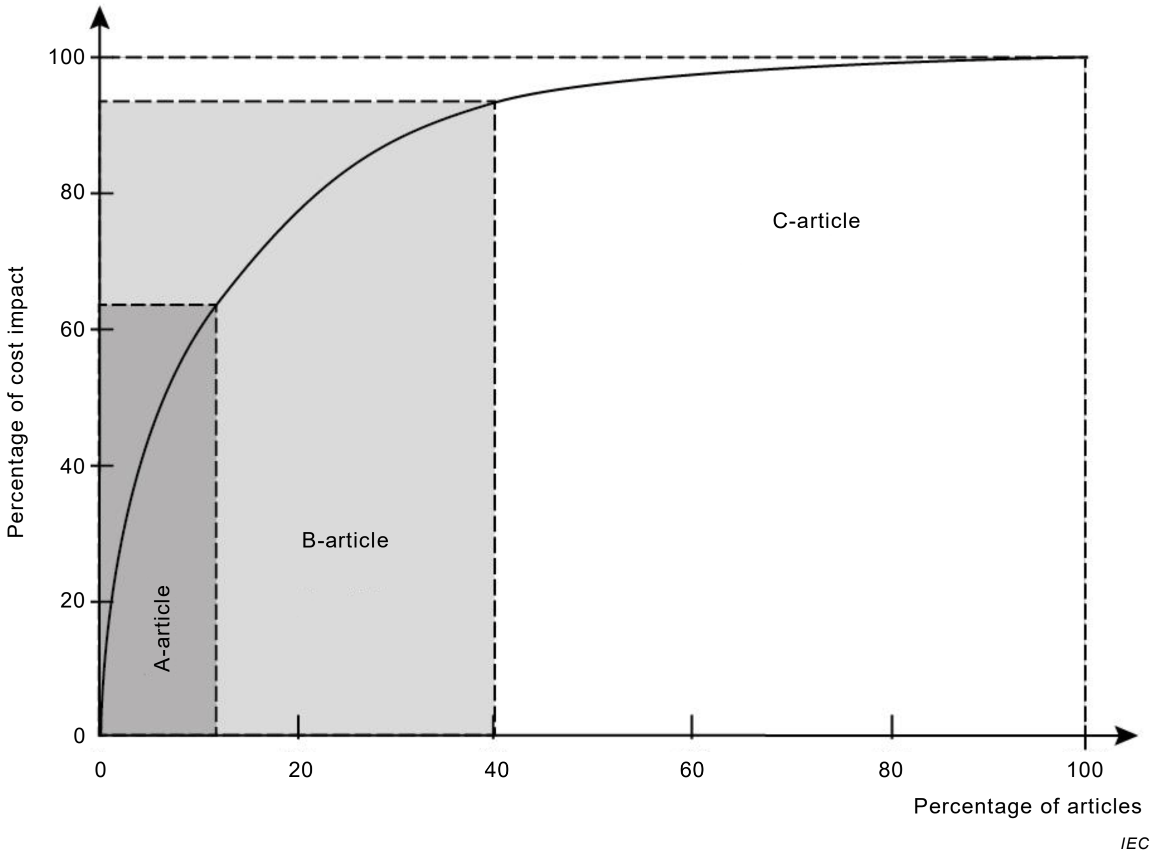


Figure 5 – Principle of an ABC-analysis

If the item's price is not known, an estimate has to be made. For prediction of the annual demand, refer to Clause 5.

Typically the item-budget-statistic shows the following results:

- only very few items, approximately 5 to 10 per cent of all items, contribute to about 65 per cent of the overall budget; these items are identified as A-articles;
- few items, approximately 25 to 30 per cent of all items, contribute to about 25 to 30 per cent of the overall budget; these items are identified as B-articles;
- many items, approximately 60 to 70 per cent of all items, contribute to about 10 to 15 per cent of the overall budget; these items are identified as C-articles.

In an inventory system, A-articles should be considered with respect to their consequence on the overall costs. It is valuable to spend more effort on planning and control of these items so that major savings can be achieved.

B-articles are subject to routine procedures. The spares manager will control in detail the stock quantities and the stock development.

C-articles are controlled by a simple system that should be automated even when this may result in slightly higher stock levels.

For the different article categories, the following processes have to be considered:

a) For A-articles:
    - detailed analyses of market, price, cost structure and value;
    - accurate supply procedures;

- particular demand forecast;
- precise inventory control;
- accurate control of the supply chain;
- careful definition of safety and reorder stocks;
- accurate calculation of cost-optimal order quantities;
- stringent control of time duration in inventory.

b) For B-articles:

- for articles in this category, intermediate procedures between A- and C-articles should be considered.

c) For C-articles:

- simplified supply procedures;
- simplified inventory control procedure;
- basic control of the supply chain;
- definition of higher safety and reorder stocks;
- simple calculation of order quantities;
- simple control of time duration in inventory.

6.1.5 Quantification of repairable items

In general, repairable items can be considered as A- or B-articles following the terminology of the ABC-analysis.

At each time of the utilization period, the same probability of failure and a constant repair turn-around time are assumed. Furthermore, it is assumed that the repair of repairable items forms a closed loop. In practice, this is not always the case since sometimes items cannot be repaired under certain conditions, such as economic reasons, wear or obsolescence.

In the following, the most important conditions and prerequisites are described, which are the basis for the quantification of repairable items.

- The failures of different items are independent of each other, i.e. the failure of an item does not cause the failure of another item at the same indenture level. If such secondary or induced failures have to be considered, a factor has to be included in the demand rate (see 5.3.3).
- The failure rate is constant over time, and material fatigue or wear is not explicitly considered.
- Constant repair turn-around times for each part are assumed, i.e. no time distribution and no dependences on repair volumes are considered.
- A closed repair cycle is assumed. Partially repairable items have to be considered with a certain probability as repairable items and for the remaining portion as non-repairable items.

The turn-around time is defined as that time which passes between the removal of a defective item from the system up to its re-arrival in the spare parts stock after the repair. In addition the transportation and administrative delay times have to be included as well.

6.1.6 Quantification of non-repairable items

In general, non-repairable items can be considered as B- or C-articles following the terminology of the ABC-analysis.

In an inventory control system, inventory position can be monitored continuously or after certain time intervals. The continuous review system triggers an order, which will be delivered after a certain lead time, as soon as the inventory is below a certain level (order point s). Another alternative is periodic review, since it considers the inventory position only after certain time intervals T, which in general are constant. It is also possible to combine these two strategies. The most common ordering policies connected with inventory control are shown in Figure 6.

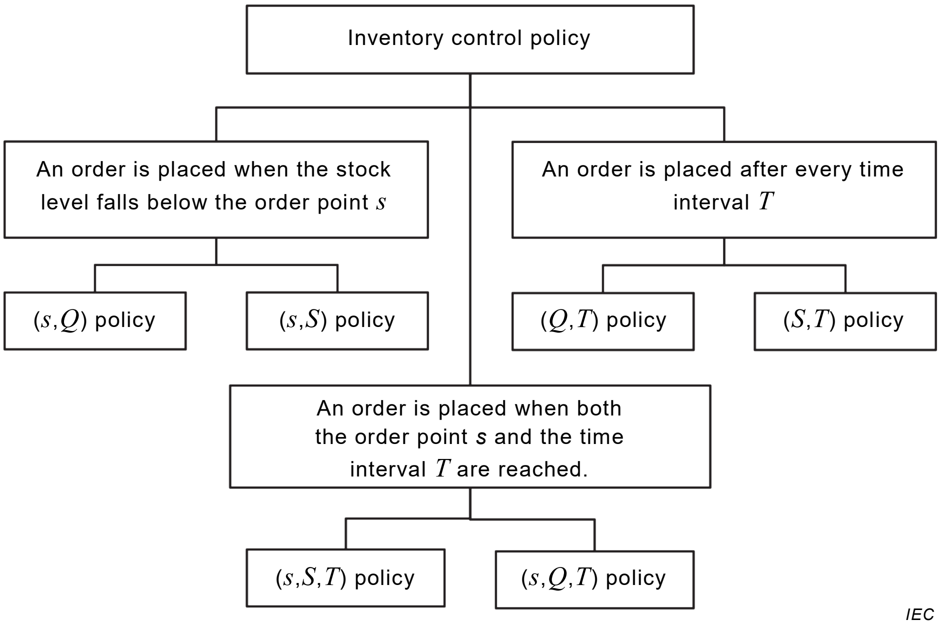


Figure 6 – Inventory control policies

Two parameters essentially control the inventory policy:

a) point in time for ordering ("When does an order have to be placed?"):
   - An order is placed when the stock level falls below a “stock limit”. This stock limit is called order point s.
   - An order is placed at every T time intervals.
   - An order is placed when both the order point s and the time interval T are accomplished, i.e. at every T time interval an order is placed only if the stock drops below order point s.

b) order quantity ("How much has to be ordered?"):
   - A quantity of Q is ordered each time, which is regarded as optimal order quantity.
   - The difference S from the maximum stock level and existing stock at the time of order is ordered.

The (S,T) policy leads to the disadvantage of alternating order quantities, which can become difficult with decreasing consumption to very small orders, so that economic conditions negotiated with the supplier may not be applicable. The (Q,T) policy can quickly lead with decreasing consumption to inflated stocks; this policy is generally the most inflexible.

The (Q,T) and (s,Q) policy will cause identical inventory processes when the demand is continuous and deterministic.

Thus the procedure for quantification of non-repairable items includes the determination of order point s and the maximum stock level S.

6.2 Strategic (critical, insurance) spare parts

As high quantities of spare parts lead to considerable costs, other factors affecting the operation of a system have to be investigated, such as

- faster repair time responsible for lead time,
- better reliability of the system/subsystem/item, or
- one or more operational systems.

A very effective method for investigation is marginal analysis, which identifies the benefits and costs of different alternatives by examining the incremental effect on total revenue and total cost caused by a very small (just one unit) change in the output or input of each alternative. Marginal analysis supports decision-making based on marginal or incremental changes to resources instead of one based on totals or averages.

In situations in which the future production of spare parts is not guaranteed or parts can only be produced with large additional costs, it may be necessary to stock parts above the required amount as a safety reserve (insurance spare parts). See IEC 62402 (Obsolescence management).

6.3 Inventory systems

Spare parts can be stocked in an inventory system in many locations, centrally or locally. Larger enterprises and/or organizations will generally stock required spare parts in a hierarchically structured inventory system. An example of such a multi-echelon system is illustrated in Figure 7. The highest is the origin which represents the central store, the second level may be the country, the third level may be the region, both are intermediate stores, finally the fourth level may be the site and called the local store.

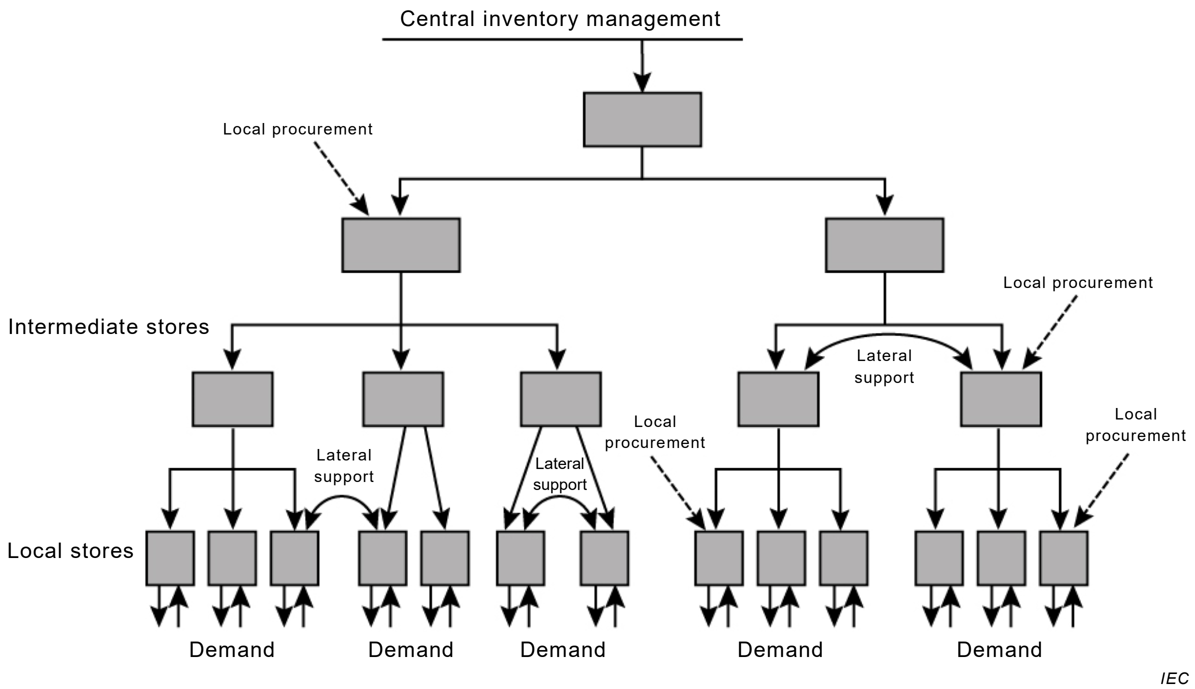


Figure 7 – Hierarchically structured inventory system

The demands within such a hierarchical inventory system are aggregated from the lowest level. At that level where the systems and/or devices are operated, the demand rate varies for different spare parts. Demands at the lowest level may change sporadically whereas at a higher level where the demand is aggregated, it becomes more evenly distributed. This effect has to be considered when selecting the appropriate distribution to perform spare parts calculations in determining the individual demand rates, the response time and the transportation time of the supplying stock to the supplied stock.

In traditional inventory systems, the management of each store only knows where to order spare parts ready for service and where to send defective items. Typically, in those situations hierarchically structured inventory systems are applied. Since computer based information systems are commonly available and in use for inventory management, it should be possible for each store manager to have information about the individual stock levels in the surrounding stores to make support more flexible. Examples are shown in Figure 7 and are named “lateral support”.

The MoEs have to be calculated from the top of the hierarchy downwards. In many cases, it may be better to establish the re-order strategy to minimize the EBO or MWT and apply a multilevel optimization to find the suitable values instead of using FRs.

Average values of MoE can be grouped in many different ways, for example:

- all stock positions at a station (MoE per location);
- all stock positions directly supporting a certain system type at a certain location;
- all stock positions, for a given primary item, that support systems directly;
- all stock positions that support systems directly; this is the total MoE experienced from the system level.

For inventory systems one can distinguish between

- multi-product-multi-inventory systems,
- single-product-multi-inventory systems, or
- single-product-single-inventory systems.

In practice, multi-product-multi-inventory systems are more common; they can be characterized as follows:

- in each stock several articles are stored;
- demand is stochastic and typically intermittent;
- delivery time is stochastic;
- dispatching takes place after fixed periods (daily, weekly, monthly) for each article individually or for several articles of a supplier;
- inventory management is mostly continuous;
- with the selection of the dispatching procedure, long-term aspects of costs are considered.

When modelling the dispatching procedure, multi-product-multi-inventory systems will be replaced by subsidiary single-product-single-inventory systems, for example, a chain of stores maintains for its assortment of goods (multi-product) with central, regional and local stocks (multi-inventory), where these are regarded separately for each product (single-product) and each site (single-inventory). The same applies to spare parts stocks which are hierarchically supplied and where different spare parts are stored.

This reduction is necessary, since stochastic-dynamic multi-product-multi-inventory systems are mostly not solvable analytically in the whole of their complexity. For spare parts stocks, reduction takes place in two steps:

- reduction of a multi-product-multi-inventory system into a system of joined single-product-multi-inventory systems determining the target quantities in the dependent supporting stocks;
- reduction of the single-product-multi-inventory system into a single-product-single-inventory system for the selection dispatching procedure at the highest stock level.

In Figure 8, an overview of the basic single-product-single-inventory models is shown. This differentiates into deterministic and stochastic models.

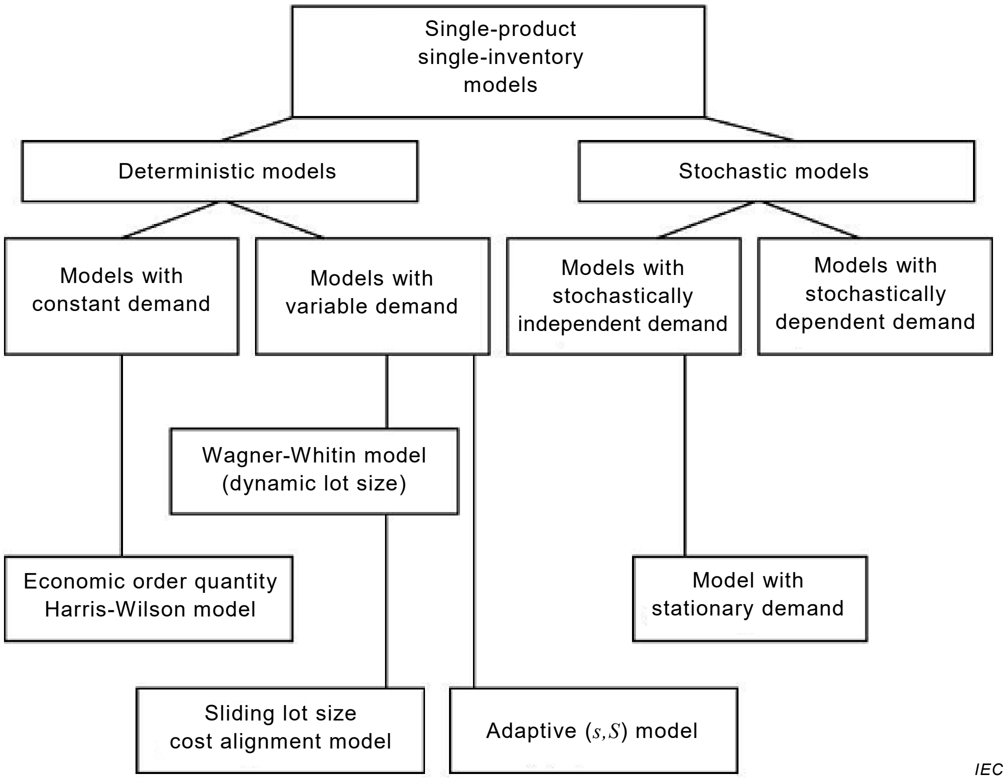


Figure 8 – Single-product-single-inventory models

By simulation methods, solutions are achievable for very complex applications, but the effort however is high. A generalization of solutions obtained beyond the case under consideration is often not possible.

6.4 Inventory optimization

Many industries such as aerospace, power plants, and manufacturing plants that use complex equipment are often faced with the difficult task of maintaining high system availability, while on the other hand, spare parts inventories have to be limited. A random failure of just one component can cause the system to be not operationally available. As downtime can be very costly, spare part inventories are required to keep the downtime to a minimal level. Therefore, it is very important to keep the probability of parts being out of stock as low as possible. However, as most parts are quite expensive, maintaining an unnecessary number of spare parts should also be avoided.

With inventory optimization, stock levels of spare parts can be optimized to support maximum availability with minimum inventory.

Maintenance policies and spare parts inventory policies should not be treated separately or sequentially as is often done in practice. To ensure availability of spare parts for an operating system, there is often a tendency of overstocking. Exorbitant inventory quantities tie up capital. The stock level of spare parts is mainly dependent on the maintenance concept. Therefore, maintenance programs should be designed to reduce both maintenance and inventory related costs.

Minimization of total inventory investment is a nonlinear integer optimization problem. Such problems are known to be hard to solve, even for a small number of items.

An overview of techniques for inventory optimization is shown in Annex C.

Procedures for the optimization of non-repairable items should also consider storage costs and order costs associated with the completion of an order. The total order quantity depends on the order cycle time, which has to be optimized. The main components of total costs are storage costs, minimum order quantities, quantity-dependent prices and cost of the completion of an order.

Cost optimization for non-repairable items entails basically an optimal order policy, i.e. optimal order quantities and optimized order points, in line with the delivery service. The computation of order quantity and the order lead date can only be accomplished independently. Large order quantities with the same boundary conditions cause wider stocks ranges, larger stocks and fewer order transactions than small order quantities. Therefore it is necessary to optimize these influencing factors and the costs of the present inventory system.

The optimization of non-repairable items is carried out on the basis of two parameters of the inventory model (see Figure 9), which are

- the order quantity Q, and
- the safety stock SS.

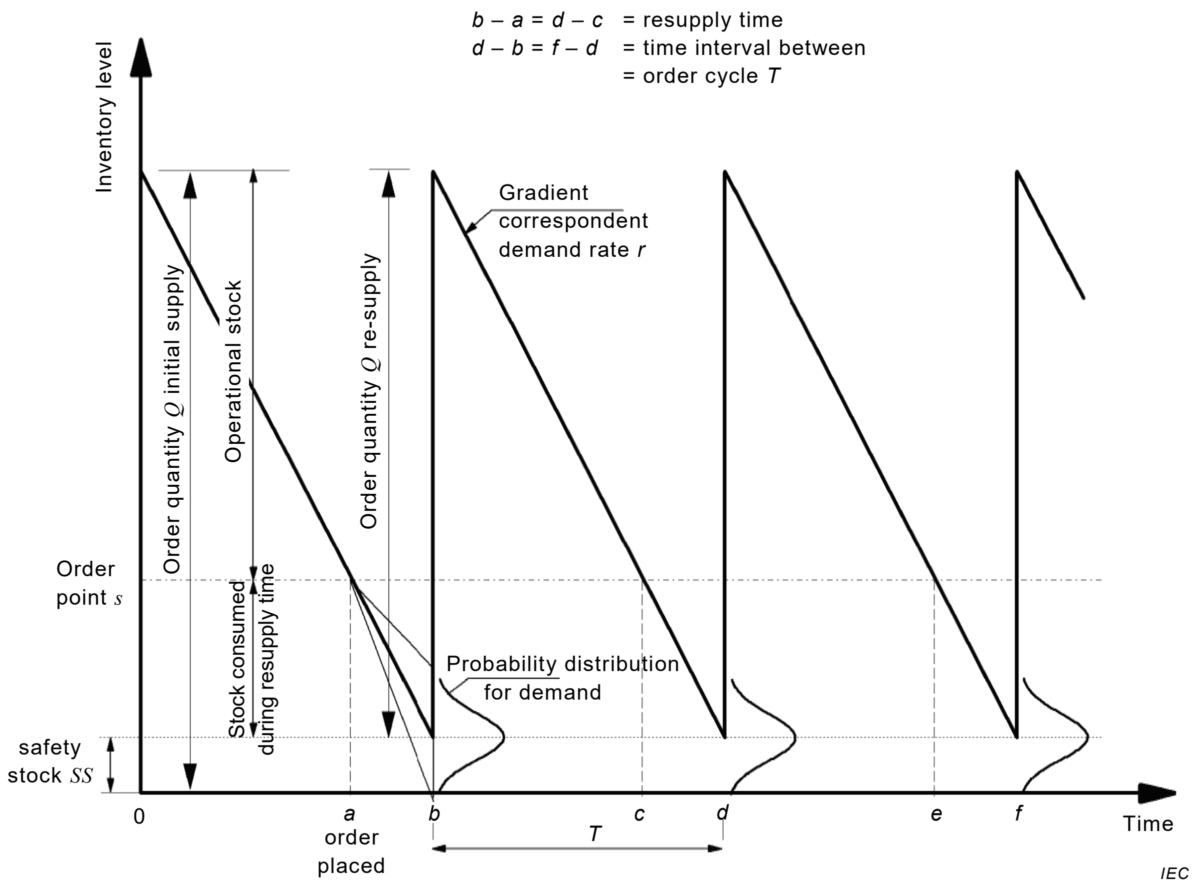


Figure 9 – Idealized inventory model for non-repairable items

The number of spare parts required can be determined on the basis of the forecasted consumption rate of an item. The operational stock is optimized so that the total costs are minimized for

- storage costs,
- indirect (order quantity-independent) procurement costs, and

- direct procurement costs.

The order quantity Q includes

- operational stock,
- stock consumed during re-supply time, and
- safety stock.

On the basis of a defined system availability, the safety stock is determined by applying probability considerations. For each individual non-repairable item, the safety stock is selected such that storage costs are minimized considering a given mean waiting time.

The safety stock of spares represents a buffer, which is to guarantee the supply readiness on fluctuations of consumption and/or the replacement times. Safety stocks are necessary in order to maintain supply readiness and thus the availability of the system. On the other hand, they entail storage costs and thus it is necessary to optimize the safety stock amounts against storage costs.

7 Spare parts documentation

7.1 Principles and objectives

All spare parts ordered should ideally have a unique identification and clearly indicate the equipment, assembly or sub-assembly to which they belong. During the provisioning process, a code should be developed and assigned to each part. The code is the link between the supportability analysis and the user, for whom it defines the approved maintenance plan.

7.2 Illustrated parts catalogue (IPC)

The IPC and/or the spare parts list are essential for maintenance and provide the link between the physical location of an item in the product and the unique identification applied for supportability.

The IPC and/or the spare parts list are usually contractual requirements for delivery to the customer. They should be tailored to suit maintenance that will be undertaken by the customer and/or other maintenance organizations.

A general approach to compiling data will present an engineering breakdown in disassembly sequence, identifying all assemblies and their individual components together with other detail parts, which cannot be assigned to assemblies, in accordance with their engineering drawings and BOMs. Sequencing of these items will be by using unique identification and it is this practice which enables production of the IPC from the same data. The engineering breakdown will be to the level which matches the customer's maintenance plans.

In addition to the engineering breakdown, the following will also be listed:

- raw materials;
- consumables;
- repair kits;
- shipment/storage parts.

When required, the presentation of the IPD should be done in a form that can be applied for more than one customer using the same system or equipment. Different configuration standards can be readily identified and data specific to each customer recorded on the same list.

Whenever there is a difference in level of breakdown required by two or more customers, the IPD compilation and presentation will have to provide the maximum breakdown required.

A data dictionary contains all the data elements required to cover the different types of information that may need to be provided for a compiled item. When compiling a record, however, it is necessary to provide only that data which is relevant to the item, and data elements have been categorized in such a way that selection of the appropriate data elements can be made in a logical and orderly fashion.

This categorization divides data elements into three groups:

- mandatory data elements which are essential in establishing an item record;
- conditional data elements used depending upon the nature of an item record;
- optional data elements introduced by special arrangements between customer and contractor.

Throughout the compilation, the categorization of parts-related and location-related data is identified. This signifies whether a data element for a given item will have the same value at every location in which the item is used (parts-related), or whether the value of a data element for a given item may differ and has to be held independently at each location (location-related). For example, an MTBF may be the same or diverse at different locations.

The compilation of data is achieved by taking information from engineering drawings and BOMs, together with other associated product definition data sources and structuring it with appropriately assigned data elements into IPD records. The hierarchical breakdown has to be reflected in the structure of the IPD, by showing the engineering relationship of assemblies and their parts, recorded as a logical order of breakdown of items. This relationship is identified using the data element indenture, which is a numerical code allocated to indicate the different levels of breakdown. Indenture “1” is used to show the top level, the next level would be shown as indenture “2”, and so on as the breakdown progresses. For all items, the quantity per next higher assembly (QPNHA) should indicate the quantity of the item fitted in one unit of the next higher assembly.

Within an IPD presentation, the overall structuring of the data may be defined by a specific "chapterization". Standard "chapterization" is introduced in many industries, such as aeronautics, railway, automotive. This identifies the chapters and sub-chapters into which the data has to be organized and hence provides values for the initial characters of the unique identifier. The sub-division of these sub-chapters into sub-sub-chapters, units and figures, in order to establish values for the remaining characters of the unique identifier, is undertaken with special regard to the particular content of each sub-chapter. This sub-division results in the creation of figures whose contents are suitable for effective and economic pictorial representation as illustrations. This compiled IPD is the basis for the creation of the illustrations used in the IP process. These same illustrations, together with specific parts of IPD, are subsequently used in the preparation of the IPC.

Particular items will be required to be listed at the end of a figure with an indenture code of "1". Items, which should be listed in this way are those which require to be included in the IPD presentation, but which are not contained in the hierarchical breakdown. It is possible for a figure to contain more than one of these types of items. The sequence in which they should be presented should be consistent with:

- storage and shipping parts;
- un-programmed devices and data carriers;
- markings (placards, decals, etc.);
- storage and shipping containers;
- repair kits;
- parts kits.

Specific items require to be contained in separate figures. Types of items may include:

- raw material;
- screws and gaskets;
- consumables;
- general tolerance figures;
- test equipment and tools;
- repair kit breakdown.

Items that are not presented in the figure should be marked as "not illustrated (NI)".

Certain conditions arise where it is only possible, or where it may be desirable, to supply items as spares, which are not identical to the OEM item. In these situations, the supplied item requires the allocation of special spares condition information including:

- providing an item in its “pre-fitted” state, for example items supplied with excess trim allowance;
- providing units complete with additional items fitted;
- providing units with items removed or supplied loose, for example special attachments, bolts, electrical conduit and seals as loose items.

These parts should be provided in a separate record with the same unique identifier as the fitted or production built items. The production built item should be listed first as a non-recommended item followed by the items carrying the appropriate data to support a recommended spare.

Particular items cannot be fitted in their “as supplied” state; they require some form of operation (such as drilling or reaming) before, or during, installation. Such items have to be identified and the appropriate information has to be provided.

A repair kit comprises a number of items supplied under a single part number which is used to undertake a manufacturer’s approved repair scheme. A kit may include standard parts, special repair parts and, where applicable, auxiliary tools and special consumables.

A parts kit is a kit which comprises a set of items such as gaskets, seals, O-rings supplied under a single part number, which should be replaced whenever the item for which the parts kit is produced is disassembled for repair or overhaul. The parts kit normally comprises items which are contained in the engineering breakdown of the equipment/component and these are identified as kit items.

For a spare parts kit, the shelf life of the individual items should be considered (see IEC 62435).

Details of the consumables (e.g. fuels, oils, lubricants, fluids, paints, adhesives, compounds, solvents and similar material) required in the operation, maintenance and repair of the equipment in accordance with the maintenance concept and support policy should be listed in a separate figure. These consumables should be grouped together in consumable types (e.g. lubricants, lacquers, solvents, cleaners). All line items contained in a consumable figure should carry not illustrated (NI) information.

When two or more items are interchangeable at a specific location, these items should be presented with the same unique identifier. These items should have the appropriate interchangeability information code assigned.

Specific information should be defined in the data dictionary and the appropriate codes have to be provided. These codes may include but are not limited to:

- interchangeability;
- special spares condition;
- "to be fitted";
- parts kit;
- repair kit.

7.3 Parts catalogue

Parts catalogues serve the communication between users and manufacturers or suppliers with spare parts needs and assist during the execution of repairs. In addition, parts catalogues are organizational resources for spare part management with the manufacturer or supplier and with the user. Parts catalogues are supplied based on agreement between manufacturers or suppliers and users.

The extent of the parts catalogue depends on the intended purpose and/or the maintenance concept and is to be agreed upon between manufacturers or suppliers and the user.

The range of information in parts catalogues is to be agreed upon by manufacturers or suppliers and the user.

8 Supply management

8.1 General

8.1.1 Activities

Supply management encompasses medium and short term activities. Supply management should ensure (see Figure 10):

- spare parts planning (strategic, budgetary, supply, workflow);
- preparation, scheduling and placing of spare parts orders;
- control of order times;
- control of turn-around time.

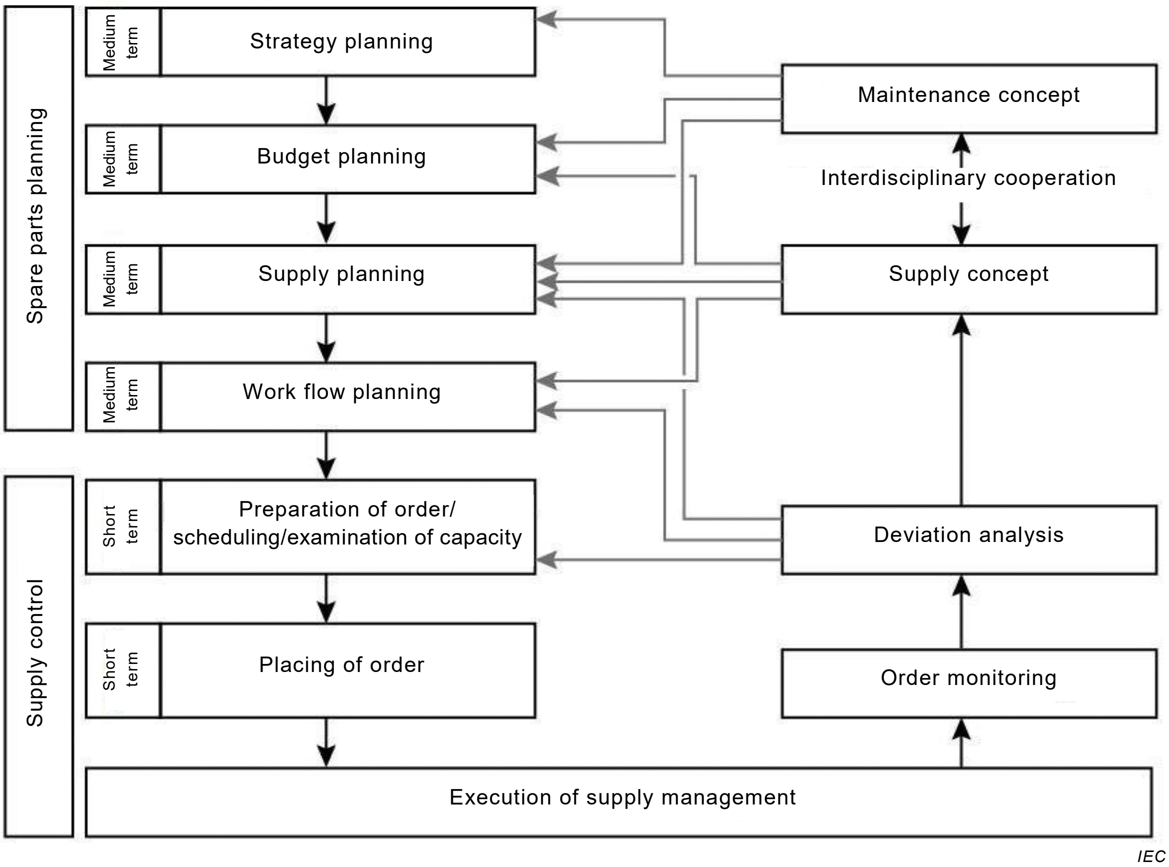


Figure 10 – Supply management activities

This document describes supply management as it affects spare parts provisioning but does not cover all aspects of supply management.

8.1.2 Economic provisioning

Prerequisites for economic provisioning of spare parts are:

- definition of tasks and responsibilities;
- personnel to perform the tasks;
- definition of measures of effectiveness, such as FR, availability, waiting time;
- organizational aids;
- approved storage techniques;
- spare parts documentation.

8.2 Sources for spare parts

Spare parts and other materials needed for maintenance are available not only from the OEM but often also from other sources. Specifications and quality of spare parts and materials are determined by the OEM and are also based on their operational environment and use. Ensuring that quality is met in a shared responsibility between the manufacturer of spare parts and the end user.

8.3 Supply policies

8.3.1 Insourcing

The term insourcing stands for the transfer of other enterprises or services to the company's area or to its direct neighbourhood with the objective of releasing transportation procedures from external influences. In the context with spare parts supply an external service provider may manage, for example, a distribution store at the premises of the operator of a system.

8.3.2 Outsourcing

The term outsourcing indicates the transfer of services to external enterprises. The enterprise tries to arrange its work "as slim as possible" ("lean production") and with regard to supply support services to maintain only those regarded as core business. As such, core business products or services are to be regarded with and/or on which the majority of the turnover is carried out. Core competence represents those parts of an enterprise, which perform something that cannot be bought at this price on the market.

In this sense it is economical to transfer or close those areas, which can be procured more economically on the market. Other criteria have to be evaluated such as market presence, and dependency on and stability of supply.

The outsourcing of supply service functions has a great impact on system support for managing service needs. The operational planning process needs to be closely integrated with the service and maintenance planning functions and in a service provider scenario; it becomes vital that there is integration from both a process and a system perspective.

8.3.3 Single sourcing

Many enterprises perform single and modular sourcing, in order to lower the complexity of the sources of supply and the costs of the procurement completion as well as to increase the transparency of the procurement process. The term single sourcing relates to the concentration on one source of procurement. The selected supplier should be competent.

With increasing quality requirements, the importance of single sourcing has grown as a supply policy. Usually common investments are conducted which result in interdependences. Close co-operation by learning, experience and synergies can lead to cost reduction, from which suppliers and customers profit and which would not have developed without co-operation.

With regard to higher contingency risk, infrastructure conditions should be established so that they ensure quick and safe supply. The co-operation needed when using a single source requires especially the ability to interact with different organizational cultures by promoting confidence, openness and acceptance of criticism with a high measure of willingness at all levels. In order to ensure close co-operation, structures should be created, which minimize interfaces and promotes optimal instead of isolated local solutions to problems. Efficient flow of material and data is an integral component of a single sourcing relationship.

By concentrating on one or a few suppliers, the cost of procurement completion and logistics costs can be reduced. Further advantages are the possible better utilization of capacity of suppliers by larger order quantities. A concentration on their own capabilities leads to cost savings, which result from the division of labour. Also reorganization of the flow of material and goods will lead to cost reduction, for example by smaller costs of capital commitment of the material and in smaller inventory costs.

When considering the economics of single-sourcing, it may be difficult to compute the costs and benefits of cooperation. Besides, it is questionable whether existing systems of accounting are able to assist with this analysis. Evaluation of the risk, which is taken by the restricting to one supplier is difficult to measure. There are some risks, such as production disturbances and interruptions, strike vulnerability, lack of recognition of a new technological development, renouncement of competition as well as potential “switching costs“, which make a later change to a supplier more difficult. Therefore, it should be examined whether the cost advantages of single sourcing are sufficiently beneficial and are counterbalanced by hard calculable risks. When considering the disadvantages of a single sourcing policy, it should be evaluated if dual sourcing is feasible, i.e. at least two suppliers should be planned for each product.

8.3.4 Global sourcing

The term global sourcing is not clearly defined despite intensive discussion in the literature. Often global sourcing is known as "international purchase" or efficient use of world-wide resources within the ranges of personnel, material, energy and capital. Global sourcing can be defined as international market cultivation in the context of the strategy of the supplying management and as systematic expansion of the procurement policy on international sources of procurement under strategic adjustment.

A set of internal and external considerations is required in order to be able to operate global sourcing effectively and efficiently. Political stability, security of trade and law belong to external considerations, and a transition from a pure purchase function to supply chain management should be implemented. Global sourcing can only become effective with extensive knowledge, management experience, good qualifications and an appropriate orientation of employees. Expanded study of the procurement market is a substantial prerequisite for obtaining the necessary information. The logistic chain should be controllable and manageable over all frontiers and jurisdictional systems and this leads to increasing complexity, global data networks and to the use of different means of transport.

The evaluation of global sourcing concepts involving the component of international purchase is mostly focused on lower delivery costs. The differences in prices are clearly and directly noticeable, however this view hides an integrated approach. The evaluation should include aspects of smaller procurement risk and higher supply security. The evaluation of the risks of currency fluctuations, interruptions of supply chains and political changes should be considered.

Increased transition to world-wide procurement leads mostly to a degradation in quality and determinability of the schedule and quantity of material streams. In order to hold a fixed service level, extended planning instruments need to be made available, for example separate control systems or higher planning frequency.

8.3.5 Concurrent sourcing

Technical systems can be procured and introduced in one or several stages. Different procedures are applicable and recommended regarding spare part quantification and procurement.

During a single-stage system installation, generally higher requirements have to be set with regard to quality of spare part quantification than with a start-up in several stages, in particular if it concerns plants or systems which are produced in a small number. Since breakdowns and first-time production difficulties cannot be excluded, suitable initial supply procedures have to be applied.

With systems that are produced in larger quantity but are procured by a single customer in a small quantity compared to the overall production volume, it can be assumed in general that spare parts with slightly changed costs can be procured within a short time. In these cases, an estimated spare part provision with stocks, which corresponds to the requirements of a consolidated operational phase, is economic and suitable. Besides, the quantification can usually rely on reliability data of other operators.

For systems with a limited group of users, which are only produced in small quantities the requirement commonly exists for a so-called life-time-buy, i.e. procurement for the entire system lifetime, since production is phased out after installation of the equipment and spare parts. Later reorders could, if generally technically possible, only be manufactured in single-unit production at a considerably higher price. This means that spare parts have to be procured concurrently with the system production.

8.3.6 Obsolescence management

The term obsolescence is used to refer to the fact that an item, in this case a spare part, is no longer procurable. In principle, all products available on the investment and consumer goods markets can be affected by obsolescence since the supply of spare parts can phase out towards the end of the product life cycle.

Any piece of equipment, tools, hardware, software, by-product, etc. can become obsolete. The obsolescence problem impacts at all stages of a product life cycle, but the effects of obsolescence are particularly great once serial production has ended. As a general principle, the obsolescence phase of a product begins immediately after the information about discontinuance is issued and the product is considered as obsolescent. Obsolescence is unavoidable, expensive and cannot be ignored.

Obsolescence management is the process of ensuring that the product is able to be manufactured and supported for its intended life. The process consists of planned and co-ordinated activities for providing availability of a product during its intended life, by the economic and practicable provision of replacement components and support activities.

Two main strategy options should be considered in obsolescence management:

- reactive strategy: react to problems of obsolescence as and when they occur;
- proactive strategy: develop and implement an obsolescence management plan in advance.

For more detailed information, refer to IEC 62402.

8.4 Planning and control of the flow of repairable spare parts

There are several flow options that can be considered for the replacement of spare parts:

- Continuous: spare parts are sent for repair immediately when they are identified as requiring repair;
- Batch: spare parts are only sent for repair when a pre-defined quantity has been reached;
- New parts: a percentage of spare parts is estimated to be beyond economic repair and these have to be ordered to keep the number of spares constant – manufacturing a complete item may take longer than a repair;
- Strip down and repair: a replacement part may comprise a number of minor parts, but it is considered more expedient to replace the larger part. Subsequent strip down identifies the minor part which then undergoes a continuous or batch repair;
- Modification: the criticality of a modification may require all spares to be modified immediately, spares to be modified only on repair, or the spare to be modified only when the repair relates to the modification. Modification can increase the turnaround time.

In addition, spares can be held in a number of locations and also there may be centres feeding a number of specific locations. This can enable an urgent spare part to be "borrowed" from another location or centre. This is particularly true for global systems.

A dynamic inventory system, which automatically monitors spare parts, provides immediate identification of potential problems, which can greatly enhance spares flow for large systems.

When the spares flow has been planned, it is also necessary to consider the time required to adequately package spares to allow for transportation and storage without damage caused by either handling or environmental exposure. In some cases, a package is designed to accommodate the quantity in a pre-determined batch.

Annex A
(informative)

Prognosis of demand

A.1 General

The starting point for all decisions is the prognosis of future demand. Three main groups of demand forecast procedures are able to be applied:

- deterministic procedures;
- statistical analysis based on consumption data;
- subjective estimation.

An overview of the forecast procedures is shown in Figure A.1.

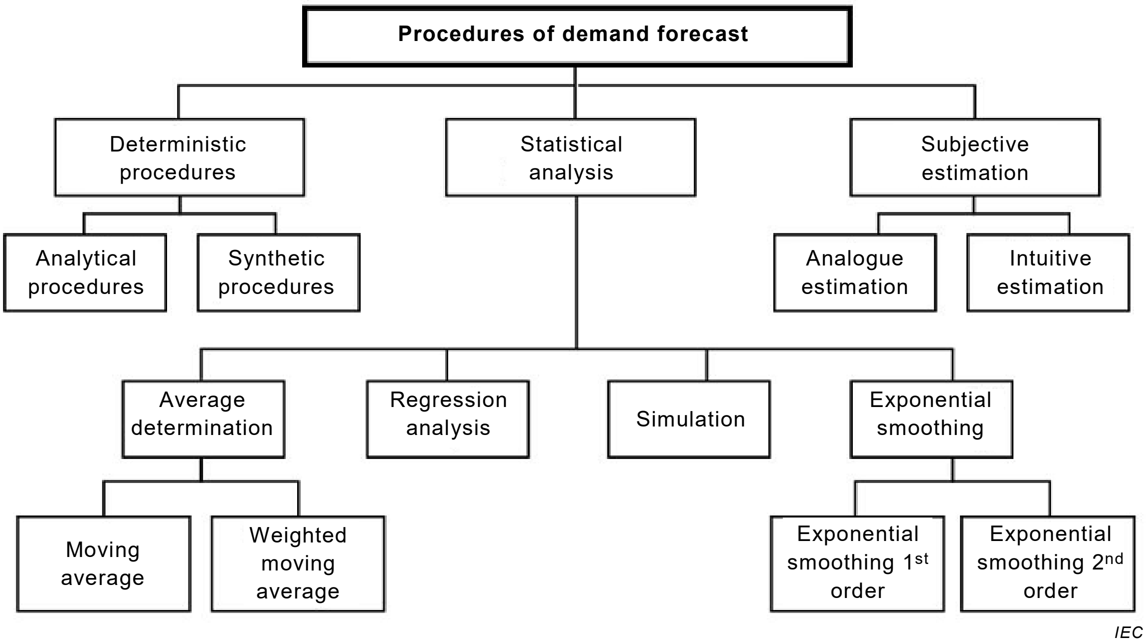


Figure A.1 – Procedures of demand forecast

A.2 Synthetic determining of demand

The most disadvantageous case is when for initial provisioning only an estimation of the failure rate is available. The amount and the demand over time of spare parts are estimated by the failure behaviour of the items. In addition, the operating conditions and intensity have to be considered.

A further important parameter for the computation of the spare part quantity is the replacement time for non-repairable items or repair turn-around time for repairable items.

If a new technical system is introduced, no past consumption figures are available for the initial provisioning of spare parts. A time series analysis cannot therefore be accomplished. Instead the need is prognosticated by means of reliability data.

In principle, there are three methods to determine reliability data:

- reliability test and/or experimental determination by component manufacturers;
- evaluation of operational data and failure statistics from users;
- reliability prediction guides, such as IEC 61709 and IEC 62308.

The first method is suitable for new components for which no empirical values are yet available. This procedure has the advantage that measurement conditions and rated loads are able to be monitored and accurately adjustable. Failure samples and failure causes can be exactly evaluated in the laboratory. Laboratory tests do require a high degree of technical sophistication and are very cost-intensive because of test times and sustained testing. Accelerated testing according to IEC 62506 and IEC 61649 can be used to reduce test time.

The second method is generally cheaper and applicable when operational data and failure statistics are available. On the basis of the failures and running times, the MTBF can be computed and computation operational reliability is determined directly, i.e. all environmental influences are able to be considered. With operation-specific failure rates, spares stocks can be optimized and measures to increase availability can be introduced.

Feedback to the equipment manufacturer may be however problematic. Only failures which have occurred during rated load without excessive load by mechanical, electrical, thermal or other environmental influences should be considered. In addition, failure causes and the type of failure (primary or secondary failure) might not be recognized accurately.

The third method, instead of laboratory tests or evaluations of operation data taking over the experience of third parties in the determination of failure rates, is a simple way to get a first rough reliability figure. Estimates of failure rates of common market components can be found in handbooks listed in IEC 61709.

A.3 Prognosis based on consumption data

A.3.1 Overview

Well-established procedures for demand forecast on the basis of observation results from the past include:

- forecast on the basis of a moving average;
- forecast on the basis of a weighted moving average;
- forecast on the basis of exponential smoothing;
- forecast on the basis of regression analysis;
- forecast on the basis of simulations.

A.3.2 Forecast on the basis of the moving average

When applying the forecast on the basis of a moving average, the values of a certain number of past time periods are averaged:

$$p_i = \frac{d_{i-1}+d_{i-2}+\cdots+d_{i-k}+d_{i-n}}{n} = \frac{1}{n}\sum_{k=1}^{n} d_{i-k} \qquad \text{(A.1)}$$

where

p_i	is the forecast for the current planning period;
$d_{i\text{-}k}$ (k = 1, 2, ..., n)	is the demand in the previous planning periods;
n	is the number of planning period considered.

This forecast procedure requires that demand data of previous periods is available. All planning periods have the same weight in this computation.

A.3.3 Forecast on the basis of the weighted moving average

A forecast on the basis of the weighted moving average applies different weighting factors for particular planning periods. When a seasonal influence is present, values of similar periods will be considered by a higher weight. If the recent demand is considered more important compared to earlier periods, weights will be ordered downwards. This procedure requires that the demand of the preceding periods and their weights are available.

$$p_i = \frac{w_1 d_{i-1} + w_2 d_{i-2} + \cdots + w_k d_{i-k} + w_n d_{i-n}}{n} = \frac{1}{n} \sum_{k=1}^{n} w_k d_{i-k} \qquad \text{(A.2)}$$

A.3.4 Forecast on the basis of exponential smoothing

A forecast on the basis of exponential smoothing represents a special case of forecasting on the basis of a weighted moving average. Exponential smoothing is a technique that can be applied to time series data to make forecasts. The procedure requires not all individual values of the past but only three data elements:

$p_{\text{predicted, old}}$	forecast for the previous planning period;
$p_{\text{actual, old}}$	actual demand for the previous planning period;
α	smoothing coefficient.

The term "smoothing" stands for a kind of averaging. The subsequent formula shows the exponential smoothing for a 1st order:

$$p_{\text{new}} = p_{\text{predicted,old}} + \alpha\left(p_{\text{actual,old}} - p_{\text{predicted,old}}\right) \qquad \text{(A.3)}$$

The smoothing coefficient α is a constant, which should be specified and has values between 0 and 1. The new prognosis p_{new} is computed from the preceding (old) prognosis $p_{\text{predicted,old}}$, corrected by the product of the smoothing coefficient α and the difference between the actual and predicted demand of the preceding planning period.

If α is set to 1, the new prognosis p_{new} is equal to the actual demand in the previous planning period. With α = 0,1 only 10 percent of deviation from predicted and actual demand is considered in the new forecast. Values of α close to 1 have a minor smoothing effect and give greater importance to recent changes in the data, values of α closer to zero have a greater smoothing effect and are less sensitive to recent changes.

By formulating Formula (A.3) as follows:

$$p_i = p_{i-1} + \alpha \cdot \left(d_{i-1} - p_{i-1}\right) = \alpha \cdot d_{i-1} + p_{i-1} \cdot (1-\alpha) \qquad \text{(A.4)}$$

and replacing in the formula p_{i-1} (the old prognosis) sequentially by the value of the preceding period the formula can be written as follows:

$$p_i = \alpha \cdot d_{i-1} + \alpha(1-\alpha) \cdot d_{i-2} + \alpha(1-\alpha)^2 \cdot d_{i-3} + \alpha(1-\alpha)^3 \cdot d_{i-4} + \ldots \qquad \text{(A.5)}$$

Formula (A.5) shows that the value applied in the prognosis is an average value which is determined on the basis of consumption in past periods and multiplied by weighting factors. The weighting factors represent a geometrical progression. The term "smoothing" stands for the fact that older values have a smaller influence than recent values.

No formally correct procedure for estimating α exists. In practice, α-values between 0,2 and 0,5 are applied. Also statistical techniques may be used to optimize the value of α. For example, the method of least squares may be used to determine the value of α for which the sum of the square differences $(p_{k-1} - d_{k-1})^2$ is minimized.

A.3.5 Forecast on the basis of regression analysis

Many observations in economic science as well as in inventory management are collected in the form of a time series. To estimate future demand, past demand history and various factors that influence the demand have to be examined. For example, research may reveal that in the past demand was growing by a constant factor from a previous planning period to a succeeding period. There are three major factors that may influence the growth of demand: the number of systems evoking demand, utilization intensity, and decreasing reliability for example due to wear-out or fatigue. Therefore, those factors have to be assessed.

Annex B
(informative)

Measures of effectiveness

B.1 General

Spare parts are considered as an important factor for the effectiveness of a support system. The provision and maintenance of an appropriate stock of spare parts is decisive for the availability of a technical system. These models do not include the consideration of cost. It may be more effective to include the cost.

The different effectiveness measurements are described in Annex B.

B.2 Stock-related measures of effectiveness

B.2.1 Fill rate (FR) and risk of shortage (ROS)

An inventory system with nominal stocks S of a given item can be described on the basis of a chain that can adopt the following states:

S, S-1, S-2, S-k ,.,S-(S-1), S-S, S-(S+1), -2,..., -∞

In the states S to S-(S-1) all demands can be fulfilled. The state S-S marks that situation in which no spare part is on stock and also no demand exists, which could not be fulfilled anyway. The fill rate is thus the sum of all probabilities $w(k)$ for the states S to S-(S-1):

$$FR = \sum_{k=0}^{S-1} w(k) \tag{B.1}$$

The risk of shortage (ROS) or probability of a stockout determines the fraction of demands which cannot be satisfied immediately from spare parts stock. In the above described chain, these are all states which are not considered for the determination of fill rate. The sum of the fill rate and risk of shortage together always result in a value of 1.

$$ROS = 1 - FR \tag{B.2}$$

Assuming a Poisson distribution for $w_k(k|\lambda T)$, the equation reads

$$ROS = \sum_{k=S}^{\infty} \frac{(\lambda T)^k}{k!} \cdot e^{-(\lambda T)} = 1 - \sum_{k=0}^{S-1} \frac{(\lambda T)^k}{k!} \cdot e^{-(\lambda T)} \tag{B.3}$$

where

T is the transitory period, i.e. repair turn-around time (including transportation times) for repairable items, replenishment lead time (including transportation times) for non-repairable items, expressed in hours;

λ is the average demand rate per hour;

S is the number of spare parts.

Assuming a constant failure rate, the average number of demands during a given time T is equal to the expression λT and can be calculated by the following formula:

$$\lambda T = N_{\text{sys}} \cdot v \cdot QPS \cdot \rho_{\text{item}} \cdot T = \frac{N_{\text{sys}} \cdot v \cdot QPS \cdot T}{MTBR} \tag{B.4}$$

where

N_{sys} is the number of systems;

v is the utilization rate (e.g. operating hours per system and calendar hour);

QPS is the quantity per system;

ρ_{item} is the replacement rate;

$MTBR$ is the mean time between replacements;

T is the transitory period, i.e. repair turn-around time (including transportation times) for repairable items, replenishment lead time (including transportation times) for non-repairable items, expressed in hours.

In Figure B.1 the FR is shown as a function of the average number of demands during a given time T (λT) and number of spares S.

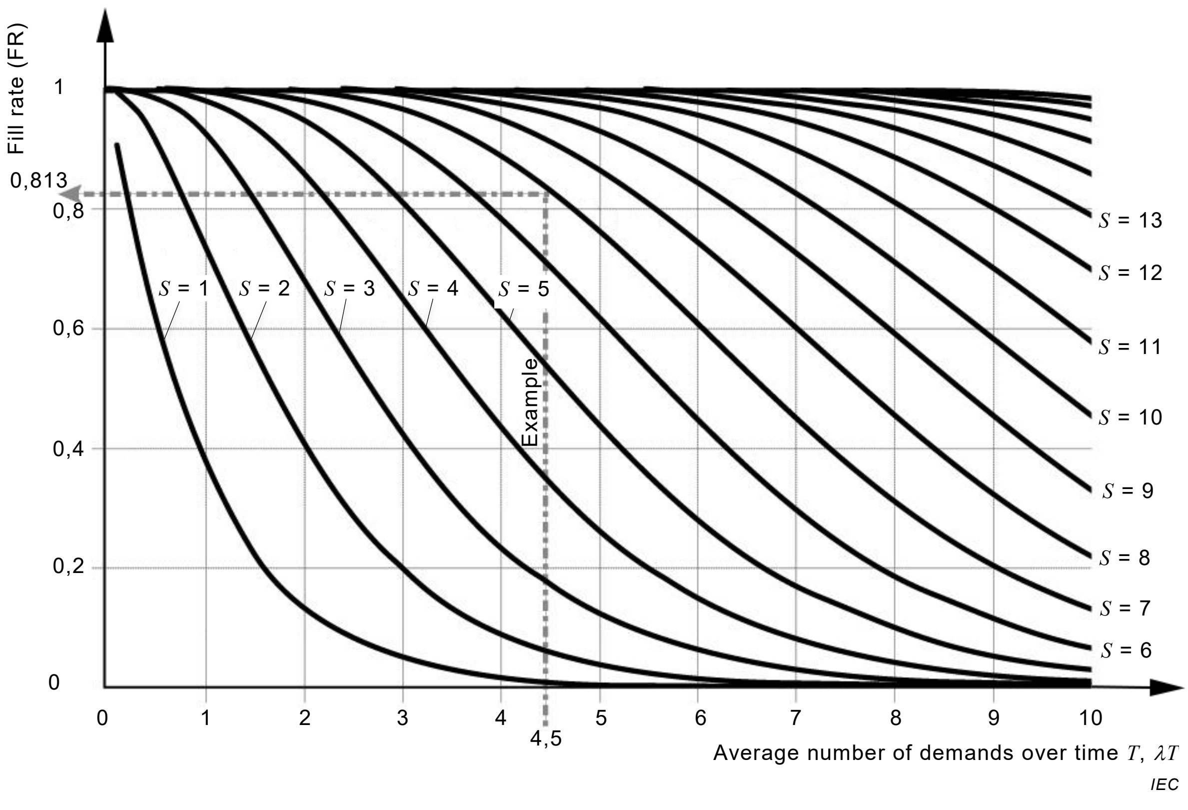


Figure B.1 – Diagram for the determination of the fill rate (FR) with a Poisson demand

Generally, the number of required spare parts can be computed with the following approximation formula for quantities greater than 30:

$$S = \left\{ \lambda T + K \cdot \sqrt{\lambda T} \right\} \tag{B.5}$$

The factor K defines the fill rate and has to be defined according to Figure B.2.

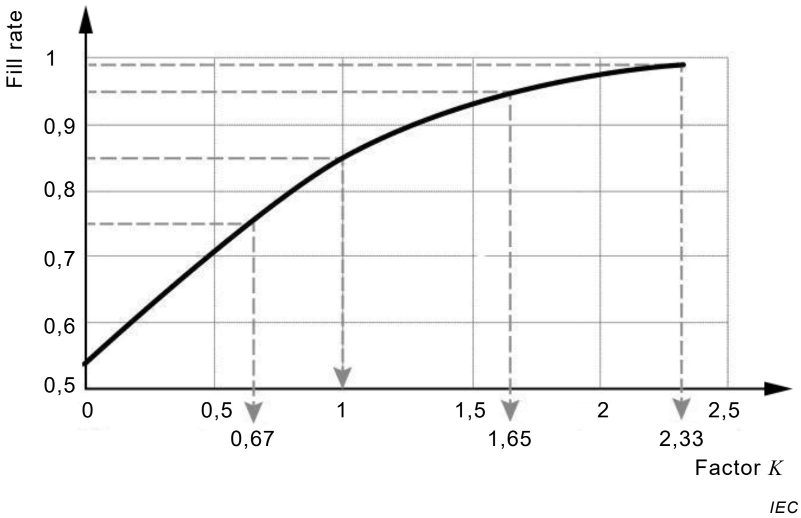


Figure B.2 – Diagram for the determination of the factor *K* for the required fill rate

B.2.2 Expected backorders (EBO)

Backorders are demands that cannot be satisfied immediately. These demands will be satisfied when a spare part is coming out of the repair cycle or the replenishment process. An inventory system with a backorder case is shown in Figure B.3.

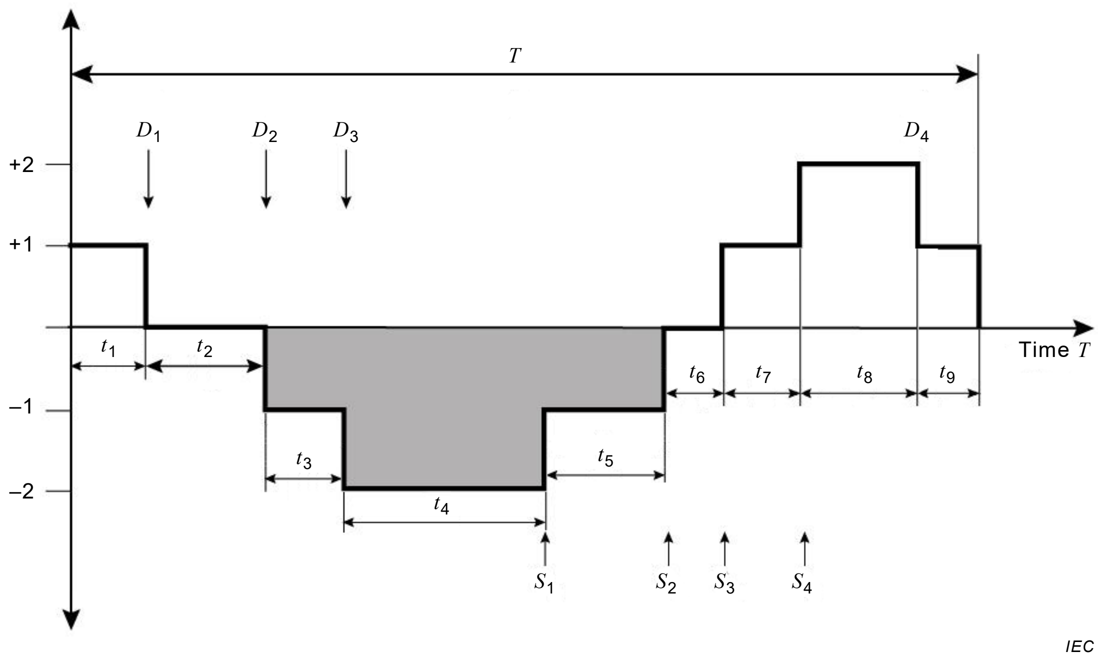


Figure B.3 – Inventory system with a backorder case

Within a considered representative period of time T, four demands of each one spare part occur: demand D_1 through D_4. At the time S_1 to S_4 a repaired spare comes out of the repair cycle. Hence, the stock level is 1 during the times t_1, t_7 and t_9, during time t_8 the stock level is 2, and during the remaining times t_2 to t_6 no spare parts are available.

The spare part's demand at the point in time D_2 is delayed and can be satisfied only after arrival of an item at time S_1. Likewise the demand at time D_3 can be satisfied only at time S_2. In the time period T, as shown in Figure B.3 two demands are backordered. The measure of "expected backorders" is an over the time weighted average value within the time period T and can be determined as follows:

$$EBO = \frac{1 \cdot (t_3 + t_4) + 1 \cdot (t_4 + t_5)}{T} = \frac{t_3 + 2 \cdot t_4 + t_5}{T} \quad \text{(B.6)}$$

The average number of backorders can also be described with the help of chains with the following states:

S, S-1, S-2, S-k,..., S-(S-1), S-S, S-(S+1), -2,..., -∞

In the states S to S-(S-1) all demands can be fulfilled. Starting from status S-(S+1), first 1 demand, then 2, etc., cannot be fulfilled directly. The backorders demands can be calculated therefore as total of all probabilities $w(k)$ for the states $k \geq S+1$, multiplied by the term (k-S); the general equation reads:

$$EBO = \sum_{k=S+1}^{\infty} (k-S) \cdot w(k) \quad \text{(B.7)}$$

Assuming a Poisson distribution for $w_k(k|\lambda T)$ the equation for the calculation of the expected backorders reads:

$$EBO = \sum_{k=S+1}^{\infty} (k-S) \cdot w_k(k|\lambda T) = \sum_{k=S+1}^{\infty} (k-S) \frac{(\lambda T)^k}{k!} \cdot e^{-(\lambda T)} \quad \text{(B.8)}$$

For practical calculations, Equation (B.8) is not suitable because of the summation to infinity. The average number of backorders can be determined by computation more easily with finite summation using the following formula:

$$EBO = (\lambda T) \cdot \frac{(\lambda T)^S}{S!} \cdot e^{-(\lambda T)} + (\lambda T - S) \cdot \left[1 - \sum_{k=0}^{S} \frac{(\lambda T)^k}{k!} \cdot e^{-(\lambda T)} \right] \quad \text{(B.9)}$$

The measure EBO is not common in practice. Conceptually, it is difficult to understand and also to measure. The reason why it is treated here in detail is the importance on the calculation of the MWT.

B.2.3 Mean waiting time (MWT)

The MWT can be calculated from the EBO by division by the demand rate λ:

$$MWT = \frac{EBO}{\lambda} \quad \text{(B.10)}$$

The MWT considers all demands, even those for which the waiting time, because of available stock, is zero. In the case of demands, which cannot be satisfied immediately, longer waiting will occur than the MWT.

In Figure B.4, the relation of MWT to the repair turn-around time T as a function of the average number of demands during a given time T (λT) and number of spares S is shown. The MWT can be calculated thus by multiplication with the repair turn-around time T.

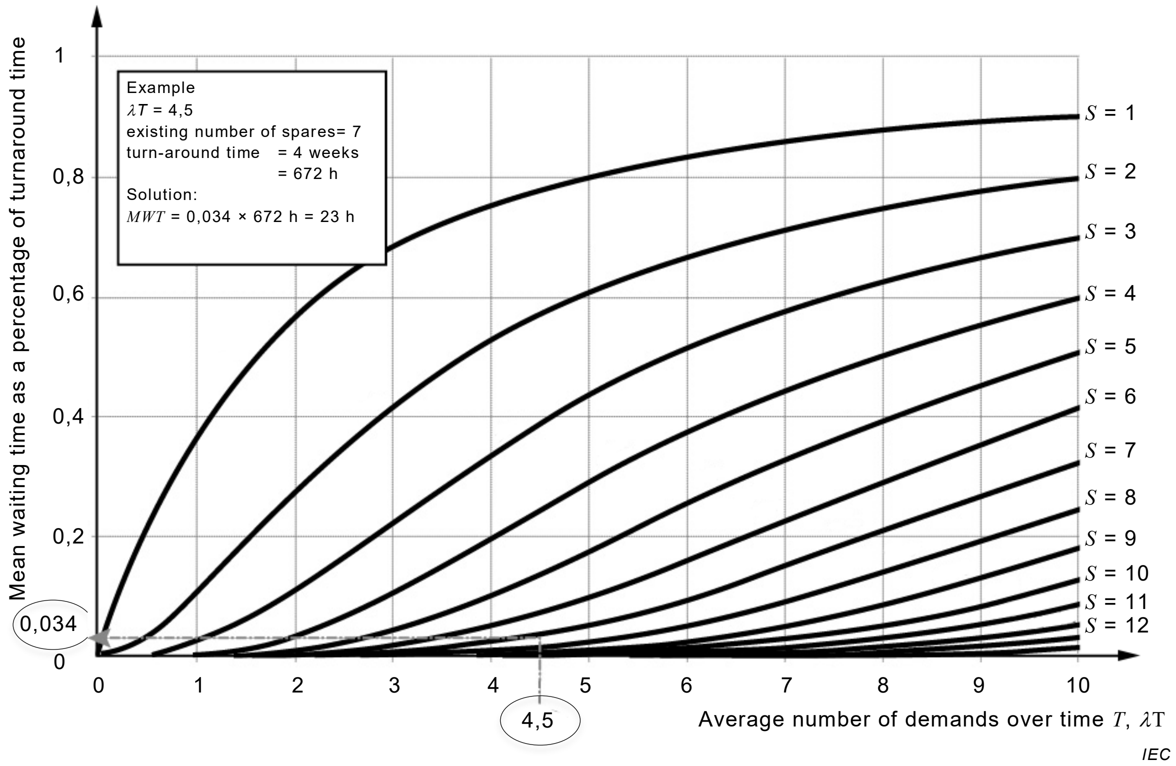


Figure B.4 – Diagram for the determination of the mean waiting time (MWT) with a Poisson demand

B.3 System-related measures of effectiveness

B.3.1 Operational system availability (A_{op})

The operational system availability (A_{op}) for steady-state operations can be calculated by the following formula:

$$A_{op} = \frac{MTBR}{MTBR + MDT} \tag{B.11}$$

where

A_{op} is the operational system availability;

$MTBR$ is the mean time between replacements;

MDT is the mean down time.

$$MDT = MRT + MLD + MWT \tag{B.12}$$

where

MRT is the mean repair time;

MLD is the mean logistic delay;

MWT is the mean waiting time.

The MRT is calculated as a weighted mean from the individual times to replace LRIs. The mean logistic delay time represents delays caused by lack of resources.

For non-continuous operational profiles, Formula (B.12) is not applicable. The determination of the practical availability with non-continuous operation has to consider the exact operational profile, the failure consequences and the repair resources. A more complex method has to be applied to determine this practical system availability, such as Monte Carlo simulation.

B.3.2 Number of systems not operationally ready (NOR)

A version of the availability measure is NOR, calculated as the average number of not operationally ready systems due to on-going repair and shortage of spares. NOR is calculated as

$$NOR = (1 - A_{\mathrm{op}}) \cdot N \tag{B.13}$$

where

A_{op} is the operational system availability;

N is the total number of systems.

Annex C
(informative)

Example: Quantification of spare parts and optimization of inventory stocks

C.1 General

The following example describes the quantification of spare parts and optimization of inventory stocks. The example refers to a product called "data communication network (DCN)". This example is taken from IEC 60300-3-3:2004. The product breakdown structure, shown in Figure C.1, lists the different elements included in the DCN.

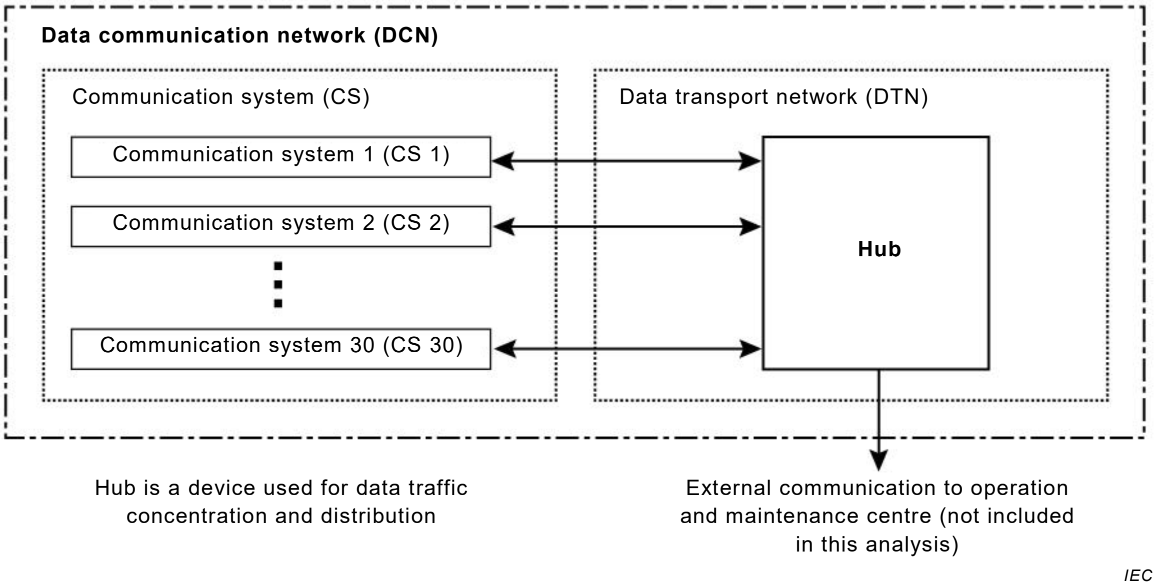


Figure C.1 – Structure of the DCN

The purpose of this example is to identify the potential spare parts, to show the information as prerequisites of the quantification, and to demonstrate the quantification and optimization process.

C.2 Product breakdown structure

To perform the required calculations for the spare part quantification a detailed product breakdown structure should be worked out. The product breakdown structure gives the breakdown of the product to lower indenture levels.

As shown in Figure C.1, the product under consideration is a data communication network (DCN) consisting of N identical communication systems (CS) and a data transport network (DTN). The data transport network contains all data links within the DCN.

Tables C.1 to C.5 present a product breakdown structure, in three indenture levels, together with some product dependability and cost data.

Table C.1 – First indenture level – Data communication network

Level 1	Description for item	Abbreviation	Required availability performance	Quantity N
P_1	Communication system	CS	All downtimes result in penalty cost	30
P_2	Data transport network	DTN	99,995 % per link	30 (1 per link)

Table C.2 – Second indenture level – Communication system

Level 2	Description for item	Abbreviation	Failure rate (z) failures / 10^6 h	Cost per item CU[a]	Quantity per next higher level
$P_{1.1}$	Power supply system	PSS	See Table C.3	See Table C.3	1
$P_{1.2}$	Main processor	MP	See Table C.4	See Table C.4	1
$P_{1.3}$	Display console	DC (RI_7)	5 per item	900	2
$P_{1.4}$	Input / output unit	IOU (RI_8)	4 per item	300	1
$P_{1.5}$	Fan system	FS	See Table C.5	See Table C.5	1

Replaceable item (RI) is to be replaced at the ‘site level’ and to be repaired at the ‘workshop level’.

[a] CU: Currency unit.

Table C.3 – Third indenture level – Power supply system

Level 3	Description for item	Abbreviation	Failure rate (z) failures / 10^6 h	Cost per item CU[a]	Quantity per next higher level
$P_{1.1.1}$	Power supply unit	PSU (RI_1)	18 per item	350	2
$P_{1.1.2}$	Power control unit	PCU (RI_2)P	4 per item	200	1
$P_{1.1.3}$	Battery[b]	BATT (NR)[c]	Negligible	100	8

[a] CU: Currency unit.

[b] The battery requires preventive replacement due to wear-out failures.

[c] NR: Non-repairable item.

Table C.4 – Third indenture level – Main processor

Level 3	Description for item	Abbreviation	Failure rate (z) failures / 10^6 h	Cost per item CU[a]	Quantity per next higher level
$P_{1.2.1}$	Central processor	CP (RI_3)	15 per item	4 000	2
$P_{1.2.2}$	Program store	PS (RI_4)	18 per item	1 000	2
$P_{1.2.3}$	Data store	DS (RI_5)	22 per item	800	4
$P_{1.2.4}$	Data bus system	DBS (RI_6)	3 per item	400	1

[a] CU: Currency unit.

Table C.5 – Third indenture level – Fan system

Level 3	Description for item	Abbreviation	Failure rate (z) failures / 10^6 h	Cost per item CU	Quantity per next higher level
$P_{1.5.1}$	Fan[b]	FAN (NR)[c]	Negligible	40	4
$P_{1.5.2}$	Alarm unit	AU (RI_9)	2 per item	80	1

[a] CU: Currency unit.

[b] The fan requires preventive replacement due to wear-out failures.

[c] NR: Non-repairable item.

C.3 Calculation of spare parts quantities and costs

The calculations in this example are based on the following prerequisites and assumptions based on estimated performance parameters, cost, and other conditions:

- mean time to restoration (MTTR) = 0,5 h;
- mean technical delay (MTD) = 0,25 h;
- mean administrative delay (MAD) = 4 h;
- useful life of a battery = 4 years;
- useful life of a fan = 9 years;
- no preventive maintenance except for batteries and fans;
- all repairable items are repaired at a central workshop;
- turn-around-time (TAT) for repairable items = 672 h (= 28 days);
- transportation time (TT) for one way: site → central workshop or reverse = 24 h (= 1 day).

In Table C.6 the results of the quantification of spare repairable items performed in IEC 60300-3-3,:2004 are shown.

Table C.6 – Investments in spare repairable items

Repairable item RI	Level	Description for item	Purchase cost per item CI	Number of spare repairable items NSRI	Total investment per SRI type CU	Mean waiting times h MWT
RI_1	$P_{1.1.1}$	Power supply unit (PSU)	350	3	1 050	1,8
RI_2	$P_{1.1.2}$	Power control unit (PCU)	200	1	200	3,6
RI_3	$P_{1.2.1}$	Central processor (CP)	400	3	12 000	1,8
RI_4	$P_{1.2.2}$	Program store (PS)	100	3	3 000	1,8
RI_5	$P_{1.2.3}$	Data store (DS)	800	6	4 800	1,0
RI_6	$P_{1.2.4}$	Data bus system (DBS)	400	1	400	3,6
RI_7	$P_{1.3}$	Display console (DC)	900	2	1 800	2,4
RI_8	$P_{1.4}$	Input/output unit (IOU)	300	1	300	3,6
RI_9	$P_{1.5.2}$	Alarm unit (AU)	80	1	80	3,6
Total					**23 630**	

In IEC 60300-3-3, the MWT was calculated by an approximation formula without assignment to a specific stock position.

Figure C.2 shows the inventory system for the DCN. There are two stock position levels: workshop level and site level.

The quantity of spare repairable items shown in Table C.6 is all stocked at the workshop level.

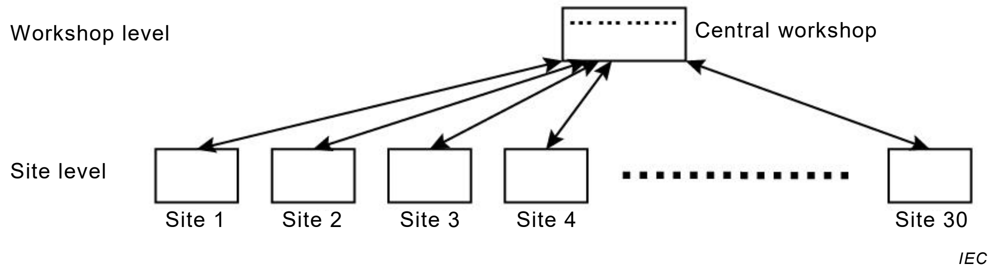


Figure C.2 – Inventory system for the DCN

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