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Petroleum, petrochemical and natural gas industries — Production assurance and reliability management

Industries du pétrole, de la pétrochimie et du gaz naturel — Assurance de la production et management de la fiabilité

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

This second edition cancels and replaces the first edition (ISO 20815:2008), which has been technically revised. The main changes compared to the previous edition are as follows:

— Clause 3: several new terms, definitions and abbreviations;

— Clause 4: new 4.1 and new Figure 2;

— Annexes A, B, C and E: minor changes;

— Annex D: various new text and new figures;

— Annex F: new text in Clause F.3, new Clause F.4, and new figure;

— Annex G and H: some changes in Clauses G.2, G.3, H.1 and H.2;

— Annex I: various changes in Clauses I.7 to I.10, I.18 to I.22, and new Clauses I.23 to I.26.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The petroleum, petrochemical and natural gas industries involve large capital investment costs as well as operational expenditures. The profitability of these industries is dependent upon the reliability, availability and maintainability of the systems and components that are used. Therefore, for optimal production availability in the oil and gas business, a standardized, integrated reliability approach is required.

The concept of production assurance, introduced in this document, enables a common understanding with respect to use of reliability technology in the various life cycle phases and covers the activities implemented to achieve and maintain a performance level that is at its optimum in terms of the overall economy and, at the same time, consistent with applicable regulatory and framework conditions.

Annexes A to I are for information only.

Petroleum, petrochemical and natural gas industries — Production assurance and reliability management

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This document describes the concept of production assurance within the systems and operations associated with exploration drilling, exploitation, processing and transport of petroleum, petrochemical and natural gas resources. This document covers upstream (including subsea), midstream and downstream facilities, petrochemical and associated activities. It focuses on production assurance of oil and gas production, processing and associated activities and covers the analysis of reliability and maintenance of the components. This includes a variety of business categories and associated systems/equipment in the oil and gas value chain. Production assurance addresses not only hydrocarbon production, but also associated activities such as drilling, pipeline installation and subsea intervention.

This document provides processes and activities, requirements and guidelines for systematic management, effective planning, execution and use of production assurance and reliability technology. This is to achieve cost-effective solutions over the life cycle of an asset development project structured around the following main elements:

— production assurance management for optimum economy of the facility through all of its life cycle phases, while also considering constraints arising from health, safety, environment, and quality;

— planning, execution and implementation of reliability technology;

— application of reliability and maintenance data;

— reliability-based technology development, design and operational improvement.

The IEC 60300-3 series addresses equipment reliability and maintenance performance in general.

This document designates 12 processes, of which seven are defined as core production assurance processes and addressed in this document. The remaining five processes are denoted as interacting processes and are outside the scope of this document. The interaction of the core production assurance processes with these interacting processes, however, is within the scope of this document as the information flow to and from these latter processes is required to ensure that production assurance requirements can be fulfilled.

The only requirement mandated by this document is the establishment and execution of the production assurance programme (PAP). It is important to reflect the PAP in the overall project management in the project for which it applies.

This document recommends that the listed processes and activities be initiated only if they can be considered to add value.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14224:2016, *Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1.1
active repair time
effective time to achieve repair of an item

Note 1 to entry: The expectation of the effective time to repair is called MART (mean active repair time).

Note 2 to entry: ISO 14224:2016 distinguishes between the terms mean active repair time (MART), mean time to repair (MTTR), mean time to restoration (MTTRes), and mean overall repairing time (MRT). See ISO 14224:2016, 3.59, 3.63, 3.64 and 3.61 for further details.

Note 3 to entry: The mean active repair time (MART) is defined as "expected active repair time" in ISO/TR 12489:2013, 3.1.34. See also ISO/TR 12489:2013, Figures 5 and 6.

[SOURCE: ISO 14224:2016, 3.2, modified — Notes 1 to 2 to entry have been added.]

3.1.2
availability
ability to be in a state to perform as required

Note 1 to entry: For a binary item, the measure of the availability is the probability to be in up state (i.e. in a state belonging to the up state class), see 3.1.59.

Note 2 to entry: In 3.1.4, the figure shows the system is available at time t_1 and unavailable at time t_2.

Note 3 to entry: See ISO 14224:2016, Annex C for a more detailed description and interpretation of availability.

Note 4 to entry: Technical or operational availability (see ISO 14224:2016, C.2.3.2 and Table E.3) or system availability can be used as derived performance measures. Case specific definition of system availability is needed to reflect the system being addressed.

Note 5 to entry: Further terms are given in ISO/TR 12489:2013.

Note 6 to entry: See Figure G.1 for further information.

[SOURCE: IEC 60050-192:2015, 192-01-23, modified — Notes 1 to 6 to entry have been added.]

3.1.3
barrier
functional grouping of safeguards or controls selected to prevent a major accident or limit the consequences

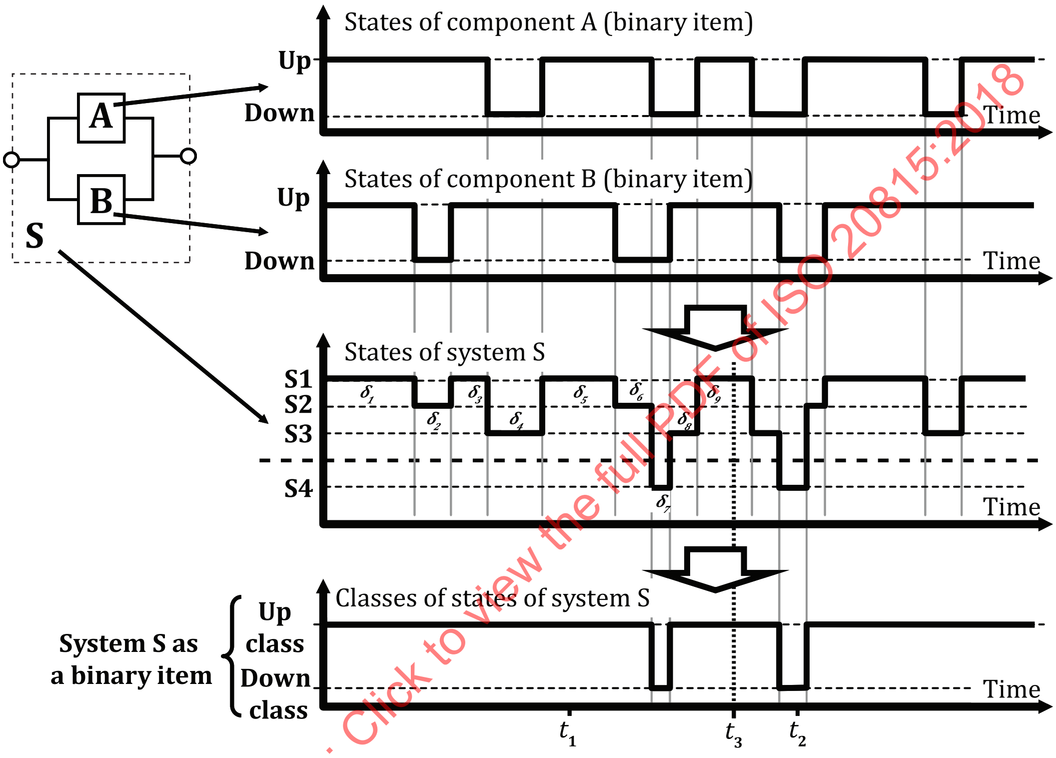
[SOURCE: ISO 17776:2016, 3.1.1]

3.1.4
binary item
item with two classes of states

Note 1 to entry: The two classes can be 'up state' and 'down state'.

EXAMPLE 1 A usual item with an up state (3.1.59) and a down state (3.1.10) is a binary item. Components A and B in the figure below are binary items.

EXAMPLE 2 A system made up of two redundant binary items, A and B, has four states: S_1 (both A and B in up state), S_2 (A in up state and B in down state), S_3 (A in down state and B in up state), S_4 (both A and B in down state). If the system is able to operate as required in states S_1, S_2 and S_3 and not able in state S_4, it is a binary item with the up state class {S_1, S_2, S_3} and the down class {S_4}. This is illustrated in the Figure showing availability behaviour of an 1oo2 system.



3.1.5
common cause failure
failures of multiple items, which would otherwise be considered independent of one another, resulting from a single cause

Note 1 to entry: See also Notes to entry for common cause failures in ISO 14224:2016, 3.5.

[SOURCE: IEC 60050-192:2015, 192-03-18, modified — Note 1 to entry has been added.]

3.1.6
condition monitoring
obtaining information about physical state or operational parameters

Note 1 to entry: Condition monitoring is used to determine when preventive maintenance may be required.

Note 2 to entry: Condition monitoring may be conducted automatically during operation or at planned intervals.

Note 3 to entry: Condition monitoring is part of condition-based maintenance. See also ISO 14224:2016, Figure 6.

[SOURCE: IEC 60050-192:2015, 192-06-28, modified — Note 3 to entry has been added.]

3.1.7
corrective maintenance
maintenance carried out after fault detection to effect restoration

Note 1 to entry: See also ISO/TR 12489:2013, Figures 5 and 6, which illustrate terms used for quantifying corrective maintenance.

[SOURCE: IEC 60050-192:2015, 192-06-06, modified — Note 1 to entry has been added.]

3.1.8
deliverability
ratio of deliveries to planned deliveries over a specified period of time, when the effect of compensating elements, such as substitution from other producers and downstream buffer storage, is included

Note 1 to entry: See Figure G.1 for further information.

3.1.9
design life
planned usage time for the total system

Note 1 to entry: to entry It is important not to confuse design life with the 'mean time to failure' (MTTF), which is comprised of several items that might be allowed to fail within the design life of the system as long as repair or replacement is feasible.

3.1.10
down state
unavailable state
internally disabled state
internal disabled state
<of an item> state of being unable to perform as required, due to internal fault, or preventive maintenance

Note 1 to entry: This concept is related to a binary item (3.1.4), which can have several down states forming the down state class of the item. All the states in the down state class are considered to be equivalent with regard to the unavailability of the considered item.

Note 2 to entry: See also Notes to entry for down state in ISO 14224:2016, 3.15.

EXAMPLE In the figure in 3.1.4, the down state class of the system S comprises only one state {S_4} and the system S is in down state at time t_2.

[SOURCE: IEC 60050-192:2015, 192-02-20, modified — Notes 1 and 2 have been added.]

3.1.11
down time
time interval during which an item is in a down state

Note 1 to entry: The down time includes all the delays between the item failure and the restoration of its service. Down time can be either planned or unplanned (see ISO 14224:2016, Table 4).

Note 2 to entry: Down time can be equipment down time (see Figure 4 and Table 4 in ISO 14224:2016), production down time (see Figures I.1 and I.2) or down time for other operations (e.g. drilling). It is important to distinguish between the equipment down time itself and the down time of the plant to which the equipment belongs.

[SOURCE: IEC 60050-192:2015, 192-02-21, modified — Notes 1 and 2 have been added.]

3.1.12
downstream
business category most commonly used in the petroleum industry to describe post-production processes

Note 1 to entry: See ISO 14224:2016, A.1.4 for further details.

[SOURCE: ISO 14224:2016, 3.17]

3.1.13
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 (i.e. a state) of that item (see 3.1.18). This is illustrated in the figure in 3.1.50 for a binary system S comprising two redundant components A and B.

[SOURCE: IEC 60050-192:2015, 192-03-01, modified — Note 1 to entry has been added.]

3.1.14
failure cause
root cause
set of circumstances that leads to failure

Note 1 to entry: A failure cause can originate during specification, design, manufacture, installation, operation or maintenance of an item.

Note 2 to entry: See also ISO 14224:2016, B.2.3 and Table B.3, which define failure causes for all equipment classes.

[SOURCE: IEC 60050-192:2015, 192-03-11, modified — Note 2 to entry has been added.]

3.1.15
failure data
data characterizing the occurrence of a failure event

Note 1 to entry: See also ISO 14224:2016, Table 6.

[SOURCE: ISO 14224:2016, 3.25]

3.1.16
failure mode
manner in which failure occurs

Note 1 to entry: See also the tables in ISO 14224:2016, B.2.6, on the relevant failure modes, which define failure modes to be used for each equipment class.

[SOURCE: IEC 60050-192:2015, 192-03-17, modified — Note 1 to entry has been added.]

3.1.17
failure rate
conditional probability per unit of time that the item fails between t and $t + \mathrm{d}t$, provided that it has been working over [0, t]

[SOURCE: ISO/TR 12489:2013, modified — Notes 1 to 4 to entry have been added.]

Note 1 to entry: See ISO 14224:2016, C.3 for further explanation of the failure rate.

Note 2 to entry: This definition applies for the first failure of binary items (3.1.4).

Note 3 to entry: Under the assumptions that the failure rate is constant and that the item is as good as new after repairs the failure rate can be estimated as the number of failures relative to the corresponding accumulated up time divided by this accumulated up time. In this case this is the reciprocal of MTTF (3.1.34). In some cases, time can be replaced by units of use.

Note 4 to entry: The estimation of the failure rate can be based on operating time or calendar time.

3.1.18
fault
<of an item> inability to perform as required, due to an internal state

Note 1 to entry: A fault of an item results from a failure, either of the item itself, or from a deficiency in an earlier stage of the life cycle, such as specification, design, manufacture or maintenance. See latent fault (ISO 14224:2016, 3.44). The down states of items A, B and S in the figure in 3.1.46 are examples of faults.

Note 2 to entry: An item made of several sub-items (e.g. a system) which continues to perform as required in presence of faults of one or several sub-items is called fault tolerant.

Note 3 to entry: See also ISO/TR 12489:2013, 3.2.2.

[SOURCE: IEC 60050-192:2015, 192-04-01, modified — Note 2 to entry has been added.]

3.1.19
fault tolerance
attribute of an item that makes it able to perform a required function in the presence of certain given sub-item faults

3.1.20
human error
discrepancy between the human action taken or omitted and that intended

EXAMPLE Performing an incorrect action; omitting a required action.

Note 1 to entry: Discrepancy with intention is considered essential in determining human error, see Reference[81].

Note 2 to entry: The term "human error" is often attributed in hindsight to a human decision, action or inaction considered to be an initiator or contributory cause of a negative outcome such as loss or harm.

Note 3 to entry: In human reliability assessment, human error is defined as any member of a set of human actions or activities that exceeds some limit of acceptability, this being an out of tolerance action or failure to act where the limits of performance are defined by the system (see Reference[78]).

Note 4 to entry: See also IEC 62508:2010 for further details.

Note 5 to entry: See also ISO/TR 12489:2013, 5.5.2.

[SOURCE: IEC 60050-192:2015, 192-03-14, modified — Notes 1 through 5 to entry have been added.]

3.1.21
instantaneous availability
A(t)
probability that an item is in a state to perform as required at a given instant

[SOURCE: IEC 60050-192:2015, 192-08-01]

3.1.22
integrity
ability of a barrier to function as required when needed

Note 1 to entry: See 3.1.2 in ISO/TR 12489:2013 for definition of safety integrity.

Note 2 to entry: There are different definitions of integrity: plant, asset, system, pipeline (see DNVGL-ST-F101:2017), well (see ISO 16530-1:2017, 3.73), mechanical, safety (see ISO/TR 12489:2013, 3.1.2), structural (see ISO 19900:—, 3.47) and technical.

3.1.23
item
subject being considered

Note 1 to entry: The item can 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.

Note 3 to entry: In this document, item can also be plant/unit and installation. See ISO 14224:2016, Figure 3.

[SOURCE: IEC 60050-192:2015, 192-01-01, modified — Note 3 to entry has been added.]

3.1.24
logistic delay
delay, excluding administrative delay, incurred for the provision of resources needed for a maintenance action to proceed or continue

Note 1 to entry: Logistic delays can be due to, for example, travelling to unattended installations, pending arrival of spare parts, specialists, test equipment and information, and delays due to unsuitable environmental conditions (e.g. waiting on weather).

Note 2 to entry: See also ISO/TR 12489:2013, Figure 5.

[SOURCE: IEC 60050-192:2015, 192-07-13, modified — Notes 1 and 2 to entry have been added.]

3.1.25
lost revenue
total cost of lost or deferred production due to down time

3.1.26
maintainability
<of an item> ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance

Note 1 to entry: Given conditions would include aspects that affect maintainability, such as: location for maintenance, accessibility, maintenance procedures and maintenance resources.

Note 2 to entry: Maintainability can be quantified using appropriate measures. See IEC 60050-192:2015, 192-07-Maintainability and maintenance support: measures.

Note 3 to entry: See Figure G.1 for further information.

[SOURCE: IEC 60050-192:2015, 192-01-27, modified — Note 3 to entry has been added.]

3.1.27
maintainable item
item that constitutes a part or an assembly of parts that is normally the lowest level in the equipment hierarchy during maintenance

[SOURCE: ISO 14224:2016, 3.48]

3.1.28
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

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

3.1.29
maintenance data
data characterizing the maintenance action planned or done

Note 1 to entry: See also ISO 14224:2016, Table 8.

[SOURCE: ISO 14224:2016, 3.51]

3.1.30
maintenance management
all activities of the management that determine the maintenance requirements, objectives, strategies, and responsibilities, and implementation of them by such means as maintenance planning, maintenance control and the improvement of maintenance activities and economics

[SOURCE: EN 13306:2017, 2.2]

3.1.31
maintenance supportability
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 (3.1.26), combined with factors external to the item that affect the relative ease of providing the required maintenance and logistic support.

Note 2 to entry: See ISO 14224:2016, Annex C for further details regarding the interpretation of maintainability.

[SOURCE: IEC 60050-192:2015, 192-01-31, modified — Note 2 to entry has been added.]

3.1.32
major accident
hazardous event that results in multiple fatalities or severe injuries; or extensive damage to structure, installation or plant; or large-scale impact on the environment

Note 1 to entry: Examples of large-scale impact on the environment are persistent and severe environmental damage that can lead to loss of commercial or recreational use, loss of natural resources over a wide area or severe environmental damage that will require extensive measures to restore beneficial uses of the environment.

Note 2 to entry: In ISO 17776:2016, a major accident is the realization of a major accident hazard.

[SOURCE: ISO 17776:2016, 3.1.12]

3.1.33
mean availability
average availability
$A(t_1, t_2)$
average value of the instantaneous availability over a given time interval $[t_1, t_2]$

[SOURCE: IEC 60050-192:2015, 192-08-01, modified — Note 1 to entry has been added.]

Note 1 to entry: The average availability is the ratio between the accumulated time spent in up state and the length of the considered period of observation. For example, in 3.1.4 the figure shows the average availability of the system over the interval $[0, t_3]$ is equal to $(\delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5 + \delta_6 + \delta_8 + \delta_9)/t_3$, i.e. $1-\delta_7/t_3$ where δ_7/t_3 is the average unavailability of the system. This formula is similar to the formula obtained for production availability calculations when only two levels, 100 % and 0 %, are considered.

3.1.34
mean time to failure
MTTF
expected time before the item fails

Note 1 to entry: See further details in ISO/TR 12489:2013, 3.1.29.

Note 2 to entry: IEC 60050-192:2015 defines MTTF as "expectation of the operating time to failure".

Note 3 to entry: See also ISO 14224:2016, Annex C.

[SOURCE: ISO/TR 12489:2013, 3.1.29, modified — Notes 1 through 3 to entry have been added.]

3.1.35
midstream
business category involving the processing, storage and transportation sectors of the petroleum industry

Note 1 to entry: See ISO 14224:2016, A.1.4 for further details.

[SOURCE: ISO 14224:2016, 3.65]

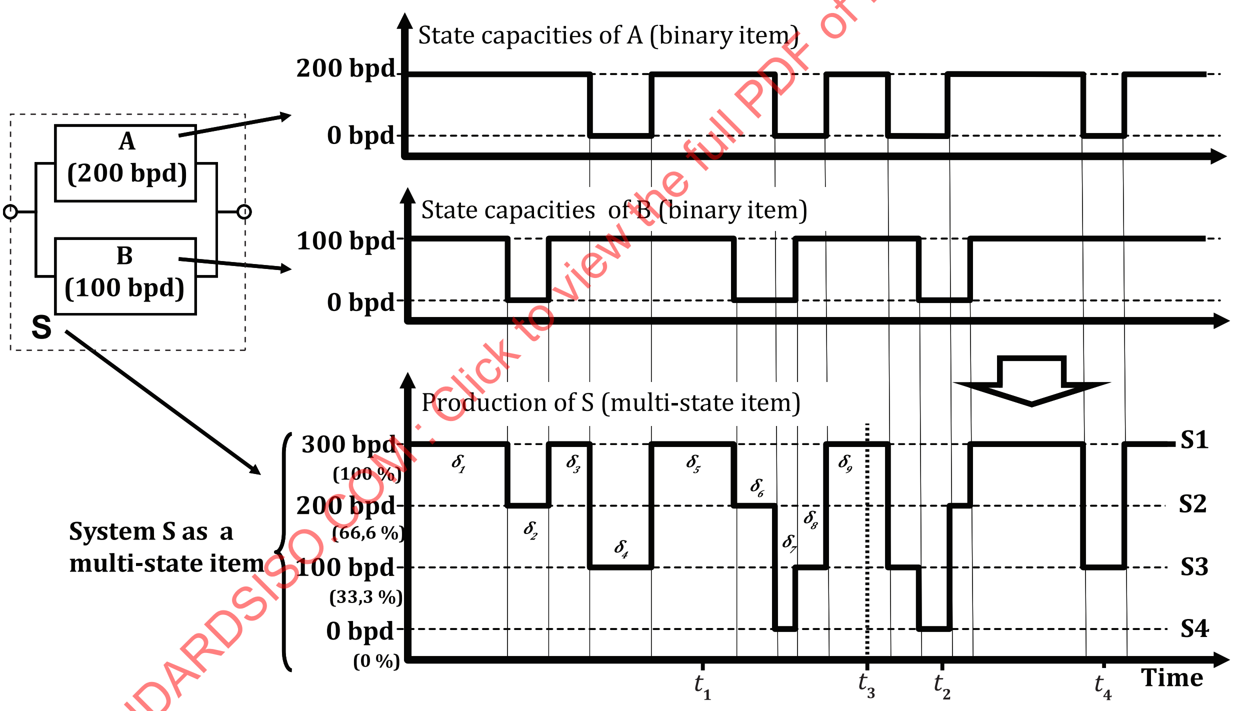
3.1.36
modification
combination of all technical and administrative actions intended to change an item

[SOURCE: ISO 14224:2016, 3.67]

3.1.37
multi-state item
item with more than two classes of states

Note 1 to entry: This is an extension of the binary items beyond the concepts of up and down states. This can characterize single items with degraded states or systems made up of several components.

EXAMPLE An oil production system comprising two wells, A and B, that can be considered as binary items (see 3.1.3) has four states: S_1 (both A and B in up state), S_2 (A in up state and B in down state), S_3 (A in down state and B in up state), S_4 (both A and B in down state). If, when they are in up state, A produces 200 bpd (barrels per day) and B produces 100 bpd, then the system has four classes of production 300 bpd, {S_1},200 bpd, {S_2}, 100 bpd, {S_3} and 0 bpd, {S_4}. With regards to oil production, it is a multi-state item. This is illustrated in the figure showing production availability behaviour of a multi-state system.



3.1.38
observation period
time period during which production performance and reliability data are recorded

3.1.39
operating state
<of an item> state of performing as required

Note 1 to entry: See also ISO 14224:2016, Table 4.

Note 2 to entry: In some applications, an item in an idle state is considered to be operating.

Note 3 to entry: The state capacities of a multi-state item characterize various levels of operation and consequently, the definition of the operating state of a multi-state item depends on the situation, for example, if:

— no other requirement is given, any state with a capacity greater than zero is an operating state;

— a minimum capacity is required, it provides the limit to split the states between up and down classes;

— a given capacity is specified, then only the states with this capacity are operating states;

— no other requirement is given, any state with a capacity greater than zero is an operating state (300 bpd, 200 bpd and 100 bpd in the figure in 3.1.37);

— a minimum capacity is required, it provides the limit to split the states between up and down classes (300 bpd, 200 bpd in the figure in 3.1.37, if the minimum allowed production is 200 bpd);

— a given capacity is specified, then only the states with this capacity are operating states (200 bpd in the figure in 3.1.37 if and only if 200 bpd are required).

[SOURCE: IEC 60050-192:2015, 192-02-04, modified — Notes 1 and 3 to entry have been added.]

3.1.40
operating time
time interval during which an item is in an operating state

Note 1 to entry: The accumulated times of various disjunct operating times interrupted by e.g. unplanned or planned down time is also called operating time.

Note 2 to entry: Sometimes the term "running time" is used instead of "operating time". Often the running time describes the active part of the operating time, see Table 4 in ISO 14224:2016. Whether rundown or start-up period is included depends on equipment, but hot-standby time is not included even though some equipment functions can be active to minimize start-up time in e.g. redundant configuration ("hot standby").

Note 3 to entry: Running hours during testing is also called running hours, even though this is at test conditions.

[SOURCE: IEC 60050-192:2015, 192-02-05, modified — Notes 1 to 3 to entry have been added.]

3.1.41
performance objective
indicative level for the desired performance

Note 1 to entry: Objectives are expressed in qualitative or quantitative terms. Objectives are not absolute requirements and may be modified based on cost or technical constraints. See further details in Annex F.

3.1.42
performance requirement
required minimum level for the performance of a system

Note 1 to entry: Requirements are normally quantitative, but may also be qualitative.

3.1.43
petrochemical
business category producing the chemicals derived from petroleum and used as feedstock for the manufacture of a variety of plastics and other related products

Note 1 to entry: See ISO 14224:2016, A.1.4 for further details.

[SOURCE: ISO 14224:2016, 3.75]

3.1.44
preventive maintenance
maintenance carried out to mitigate degradation and reduce the probability of failure

Note 1 to entry: See also condition-based maintenance, and planned (scheduled) maintenance.

[SOURCE: IEC 60050-192:2015, 192-06-05]

3.1.45
production assurance
activities implemented to achieve and maintain a performance that is at its optimum in terms of the overall economy and at the same time consistent with applicable framework conditions

Note 1 to entry: Production assurance in this document is not only limited to cover production of oil and gas, but can also be other activities such as drilling operations, downhole well intervention, subsea intervention, offshore loading operations, for which production assurance activities and reliability management are needed.

Note 2 to entry: Production assurance activities relate closely to the integrity management of the installations. See definition of integrity in 3.1.22.

3.1.46
production availability
ratio of production to planned production, or any other reference level, over a specified period of time

Note 1 to entry: Production availability is an extension of the mean availability (3.1.33) to deal with multi-state items. It is the ratio between the accumulated production delivered over a given interval of time and a reference production level defined for this interval. For example, in 3.1.4, the figure shows the production availability of the system over the interval $[0, t_3]$ is equal to $[300 \cdot (\delta 1 + \delta_3 + \delta_5 + \delta_9) + 200 \cdot (\delta_2 + \delta_6) + 100 \cdot (\delta_4 + \delta_8)] / (300 \cdot t_3)$ provided the reference production level is 300 bpd at any time. By dividing by 300, this formula can also be written $[(\delta_1 + \delta_3 + \delta_5 + \delta_9) + 66{,}6\ \% \cdot (\delta_2 + \delta_6) + 33{,}3\ \% \cdot (\delta_4 + \delta_8)] / t_3$.

Note 2 to entry: This measure is used in conjunction with analysis of delimited systems without compensating elements such as substitution from other producers and downstream buffer storage. Battery limits need to be defined in each case.

Note 3 to entry: See G.1 and Figure G.1 for further information. Examples of production loss categories (or time loss categories) are shown in Tables G.1 to G.6.

Note 4 to entry: Production efficiency (PE) is a term often used by operators for historic production availability in the operating phase and is a reported measure, but is in principle the same measure as predicted production availability that is a modelled measure. This document uses the term production availability.

Note 5 to entry: For offshore and onshore loading systems, some special performance measures exist when undertaking loading performance analyses, see further details of such metrics in I.26.

3.1.47
production performance
capacity of a system to meet demand for deliveries or performance

Note 1 to entry: Production availability, deliverability or other appropriate measures can be used to express production performance.

Note 2 to entry: The use of production performance terms should specify whether it represents a predicted or historic production performance.

3.1.48
production performance analysis
systematic evaluations and calculations carried out to assess the production performance of a system

Note 1 to entry: The term should be used primarily for analysis of whole systems, but may also be used for analysis of production unavailability of sub-systems. Annex D provides guidance for planning and reporting such analysis, and parts of Annex D can also be useful for loading performance analysis.

Note 2 to entry: Loading performance analysis is a particular type of production performance analysis focussing on offshore and onshore loading operations, which e.g. use metocean data to analyse weather impact on such operations (see I.25 and I.26).

3.1.49
redundancy
existence of more than one means for performing a required function of an item

Note 1 to entry: See ISO 14224:2016, C.1.2 for further details, where passive (cold), active (hot) standby and mixed redundancy are described.

Note 2 to entry: Redundancy in IEC 61508-1:2016 is called "fault tolerance".

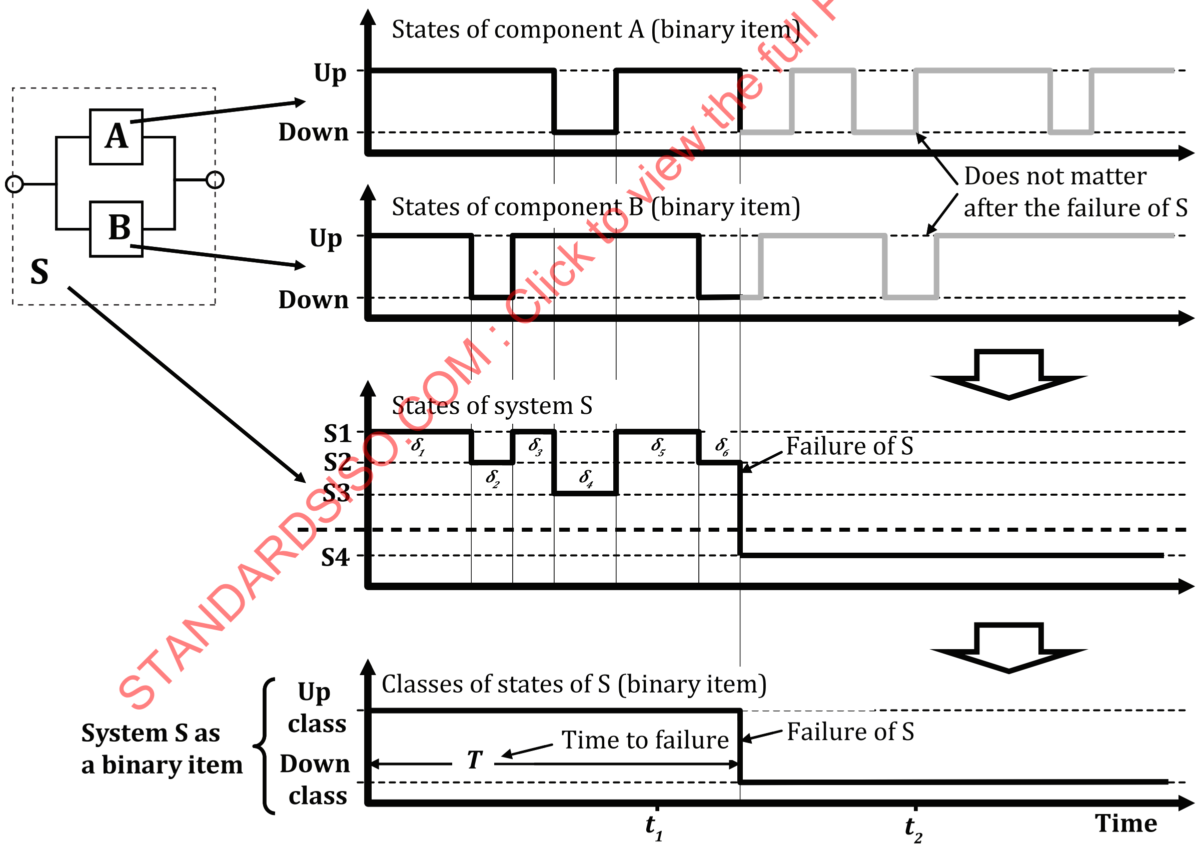
Note 3 to entry: IEC 60050-192:2015, 192-10-02 defines redundancy as "provision of more than one means for performing a function".

[SOURCE: ISO 14224:2016, 3.80]

3.1.50
reliability
ability of an item to perform a required function under given conditions for a given time interval

Note 1 to entry: The term "reliability" is also used as a measure of reliability performance and may also be expressed as a probability (see 3.1.57).

Note 2 to entry: In the figure below reliability is illustrated for a system S comprising two redundant components A and B. The system is reliable all over the interval [0, t_1] but has had a failure during [0, t_2]. See also Figure G.1 for further information.



[SOURCE: ISO 14224:2016, 3.81, modified — Notes 1 and 2 to entry have been added.]

3.1.51
reliability data
data for reliability, maintainability and maintenance support performance

[SOURCE: ISO 14224:2016, 3.84]

3.1.52
reliability management
activities undertaken to achieve reliability related performance objectives and requirements

Note 1 to entry: Reliability management reflects production assurance activities on equipment and system level. In project/product–development and design phases this is often called “reliability engineering”.

Note 2 to entry: A reliability management programme (RMP) can be used to describe such activities, see A.1.

3.1.53
required function
function, or combination of functions, of an item that is considered necessary to provide a given service

[SOURCE: ISO 14224:2016, 3.83]

3.1.54
risk
combination of the probability of an event and the consequences of the event

Note 1 to entry: This definition is based on ISO/IEC Guide 51:2014, 3.9 that defines risk as combination of the probability of occurrence of harm and the severity of that harm, where the probability of occurrence includes the exposure to a hazardous situation, the occurrence of a hazardous event and the possibility to avoid or limit the harm. “Harm" has been replaced by "event" in the definition to cope with production assurance purpose. It is also similar to the definition of the “level of risk” given in ISO Guide 73:2009, 3.6.1.8 (i.e. “combination of consequences and their likelihood”).

Note 2 to entry: Events leading to production losses are considered within the production assurance field.

3.1.55
risk register
record of information about identified risks

[SOURCE: ISO Guide 73:2009, 3.8.2.4]

3.1.56
state capacity
state efficiency
processing ability of an item state

Note 1 to entry: The capacity of an item state is related to the amount of production the item is able to produce or process in this state. For example, in the figure in 3.1.33, component A has a capacity of 200 bpd.

EXAMPLE 1 A single oil production well with two states (binary item, 3.1.4) has, for example, a capacity of 100 barrels per day (bpd) when it is in up state and of 0 bpd when it is in down state (see component B in the figure in 3.1.33).

EXAMPLE 2 An oil production system made up of two wells, A and B, producing respectively 200 bpd and 100 bpd, has four states. This is illustrated in the figure in 3.1.37:

— S_1 (A and B producing) : capacity = 300 bpd;

— S_2 (A producing alone) : capacity = 200 bpd;

— S_3 (B producing alone) : capacity = 100 bpd;

— S_4 (A and B failed) : capacity = 0 bpd.

When the reference value is non-ambiguous, the capacity can be given in percentage. For example, with regard to the maximum capacity of the producing system, the capacity of S_1 is 100 %, the capacity of S_2 is 66,6 %, the capacity of S_3 is 33,3 % and the capacity of S_4 is 0 %.

3.1.57
survival probability
reliability <measure>
$R(t)$
likelihood of the continued functioning of an item

Note 1 to entry: This likelihood is calculated by using Formula (1):

$$R(t) = \Pr(T > t) \quad (1)$$

where $\Pr(T > t)$ is the probability that the time to failure of an item, T, is greater than t, a time equal to or greater than 0.

Note 2 to entry: Reliability is illustrated in the figure in 3.1.50 for a system S comprising two redundant components A and B. As $T > t_1$ the system is reliable all over the interval $[0, t_1]$ and is surviving at time t_1. As $T < t_2$ the system is not surviving at time t_2.

3.1.58
technology qualification
process of providing evidence that the technology will perform as required for the specified application area

Note 1 to entry: The requirements include both functional (technical and operational) and associated reliability requirements for its design life. Application area refers to the operating conditions, environment or purpose for which the technology will be used.

Note 2 to entry: See further information in C.3 and I.21.

3.1.59
up state
available state
<of an item> state of being able to perform as required

Note 1 to entry: This concept is related to a binary item (3.1.4), which can have several up states forming the up state class of the item. All the states in the up state class are considered to be equivalent with regard to the availability of the considered item.

Note 2 to entry: Up state relates to the availability performance (3.1.2) of the item.

Note 3 to entry: See also ISO/TR 12489:2013, Figure 5.

EXAMPLE In the figure in 3.1.4, the up state class of the system S comprises three states {S_1, S_2, S_3} and the system is in up state at time t_1.

[SOURCE: IEC 60050-192:2015, 192-02-01, modified — Notes 1 to 3 to entry have been added.]

3.1.60
up time
time interval during which an item is in an up state

Note 1 to entry: See also ISO/TR 12489:2013, Figure 3.

Note 2 to entry: Mean up time is defined in IEC 60050-192:2015 as “expectation of the up time”.

[SOURCE: ISO 14224:2016, 3.97]

3.1.61
upstream
business category of the petroleum industry involving exploration and production

Note 1 to entry: See ISO 14224:2016, A.1.4 for further details.

[SOURCE: ISO 14224:2016, 3.98]

3.1.62
variability
variations in performance measures for different time periods under defined framework conditions

Note 1 to entry: The variations can be a result of the down time pattern for equipment and systems or operating factors, such as wind, waves and access to certain repair resources.

3.2 Abbreviations

ALT	accelerated life testing
BBN	Bayesian belief network
BOP	blowout preventer
bpd	barrels per day
CAPEX	capital expenditures
CMMIS	computerized maintenance management information system
DHSV	downhole safety valve
ESD	emergency shut down
FAT	factory acceptance test
FEED	front-end engineering and design
FMEA	failure modes and effects analysis
FMECA	failure modes, effects and criticality analysis
FN	flow network
FNA	flow network analysis
FPSO	floating production, storage and offloading
FSU	floating storage unit
FTA	fault tree analysis
HALT	highly accelerated life testing
HAZOP	hazard and operability (study)
HASS	highly accelerated stress screening
HSE	health, safety and environment
ITT	invitation to tender
KPI	key performance indicator
LCC	life cycle cost
LNG	liquefied natural gases
LOSTREV	lost revenue

LTE	life time extension
MART	mean active repair time
MDT	mean down time
METBF	mean elapsed time between failures
MODU	mobile offshore drilling unit
MPA	Markov process analysis
MRT	mean overall repairing time
MTTF	mean time to failure
MTTR	mean time to repair
MTTRes	mean time to restoration
MUT	mean up time
NPV	net present value
OPEX	operational expenditure
PAP	production assurance programme
PE	production efficiency
PFD	process flow diagrams
PID	process instrumentation diagrams
PM	preventive maintenance
PN	Petri nets
PNA	Petri net analysis
POR	performance and operability review
QA	quality assurance
QRA	quantitative risk analysis
RBD	reliability block diagram
RBI	risk-based inspection
RCM	reliability-centred maintenance
RM	reliability and maintainability
RMP	reliability management programme
ROV	remote operated vehicle
SAT	site acceptance test
SCM	subsea control module

SEM	subsea electronic module
SIL	safety integrity level
SIMOPS	simultaneous operations
SISV	subsea intervention and support vessel
SIT	system integration test
SRA	structural reliability analysis
SSIV	subsea isolation valve
TNC	technology novelty category
TQP	technology qualification programme
TRL	technology readiness level

4 Production assurance and decision support

4.1 Users of this document

This document is intended for users such as the following:

— Installation/plant/facility: Operating facility, e.g. safety, maintenance and engineering personnel.

— Owner/operator/company: Reliability staff or others analysing or responsible for production assurance, reliability management and associated activities. Other stakeholders are technology developers, concept and system planners, HSE staff, integrity management, maintenance management and professional subject-matter experts that manage and assess plants/system/equipment performance with respect to production assurance (production availability, system availability, equipment reliability, etc.).

— Manufacturer/designer and supplier: Use of reliability management activities in technology development, technology qualification, system design to ensure product quality and improvements, etc.

— Authority/regulatory body: Regulatory requirements that can refer to this document to enhance HSE, production availability, system availability, maintenance and resource utilisation.

— Consultant/contractor: Use of production assurance activities to support reliability management and undertaking reliability studies, analysis of production availability, system availability, maintenance, etc.

4.2 Framework conditions

The objective associated with systematic production assurance is to contribute to the alignment of design and operational decisions with corporate business objectives. Production assurance and reliability management activities also support quality management (see ISO 9000:2015, ISO 9001:2015 and ISO/TS 29001:2010).

In order to fulfil this objective, technical and operational measures as illustrated in Figure 1 may be used during design or operation to influence the production performance. Figure 1 shows measures that to a greater or lesser extent can have an effect on production performance. Some of these measures are purely technical and it is necessary that they will be adhered to in design; others are related purely to operation. Most of the measures have both technical and operational aspects, e.g. a bypass cannot be used in the operational phase unless provisions have been made for it in the design phase. In addition, there are dependencies between many of the listed measures.

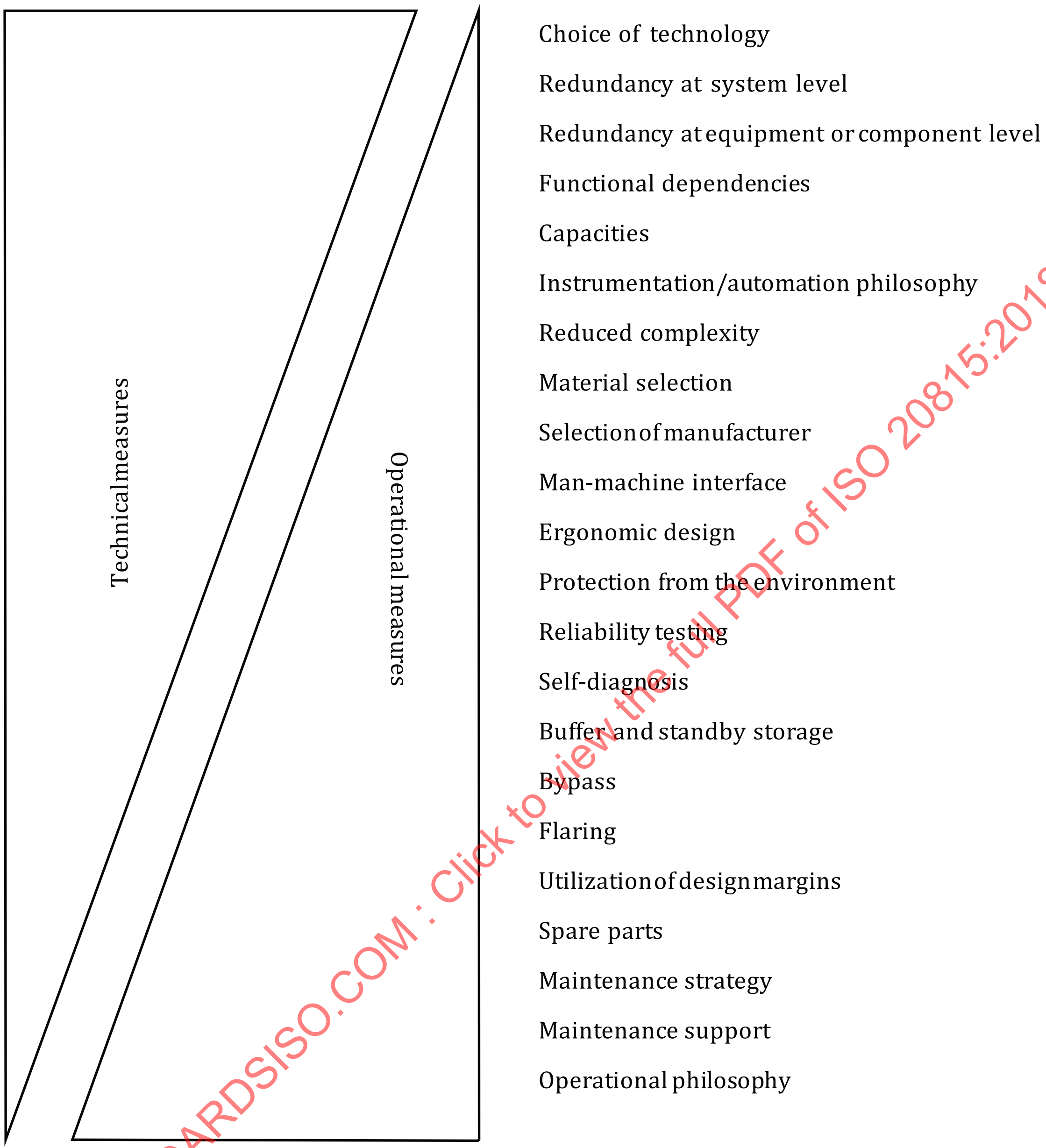


Figure 1 — Typical technical and operational measures that affect production performance

This imposes two important recommendations for production assurance to be efficient:

— production assurance should be carried out throughout all project design and operational phases;

— production assurance should have a broad coverage of project activities.

An overview of cost and revenue factors to considered in conjunction with the economic optimization is shown in Figure 2. These factors can be used to better prioritize and understand the production assurance activities with respect to life cycle cost elements (CAPEX, OPEX and LOSTREV). The economic decision criteria depend on company as well as the business context (e.g. concept selection, field development, system configuration) that is subject to decision.

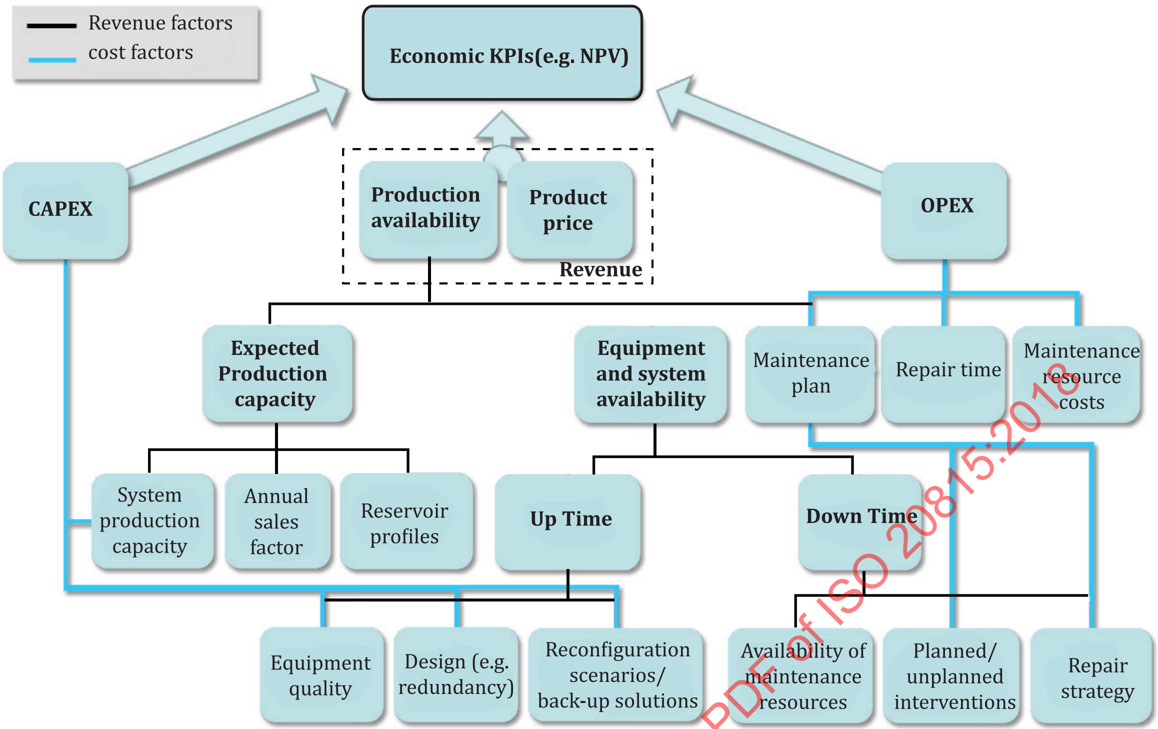


Figure 2 — Business model: Influence factors of production assurance on project economy

4.3 Optimization process

The main principle for optimization of design or selection between alternative design solutions is economic optimization within given constraints and framework conditions. The achievement of high performance is of limited importance, unless the associated costs are considered. Therefore, this document can be considered together with ISO 15663 (all parts).

Examples of constraints and framework conditions that affect the optimization process are:

— statutory health, safety and environmental regulations;

— requirements for safety equipment resulting from the risk analysis and the overall safety acceptance criteria;

— requirements to design or operation given by statutory and other regulatory bodies' regulations;

— project constraints, such as budget, implementation time, national and international agreements;

— conditions in the sales contracts;

— technical constraints.

The optimization process can be seen as a series of steps as follows (see Figure 3 for an illustration).

a) Assess the project requirements and generate designs that are capable of meeting the project requirements.

b) Identify all statutory, regulatory and other framework requirements that apply to the project.

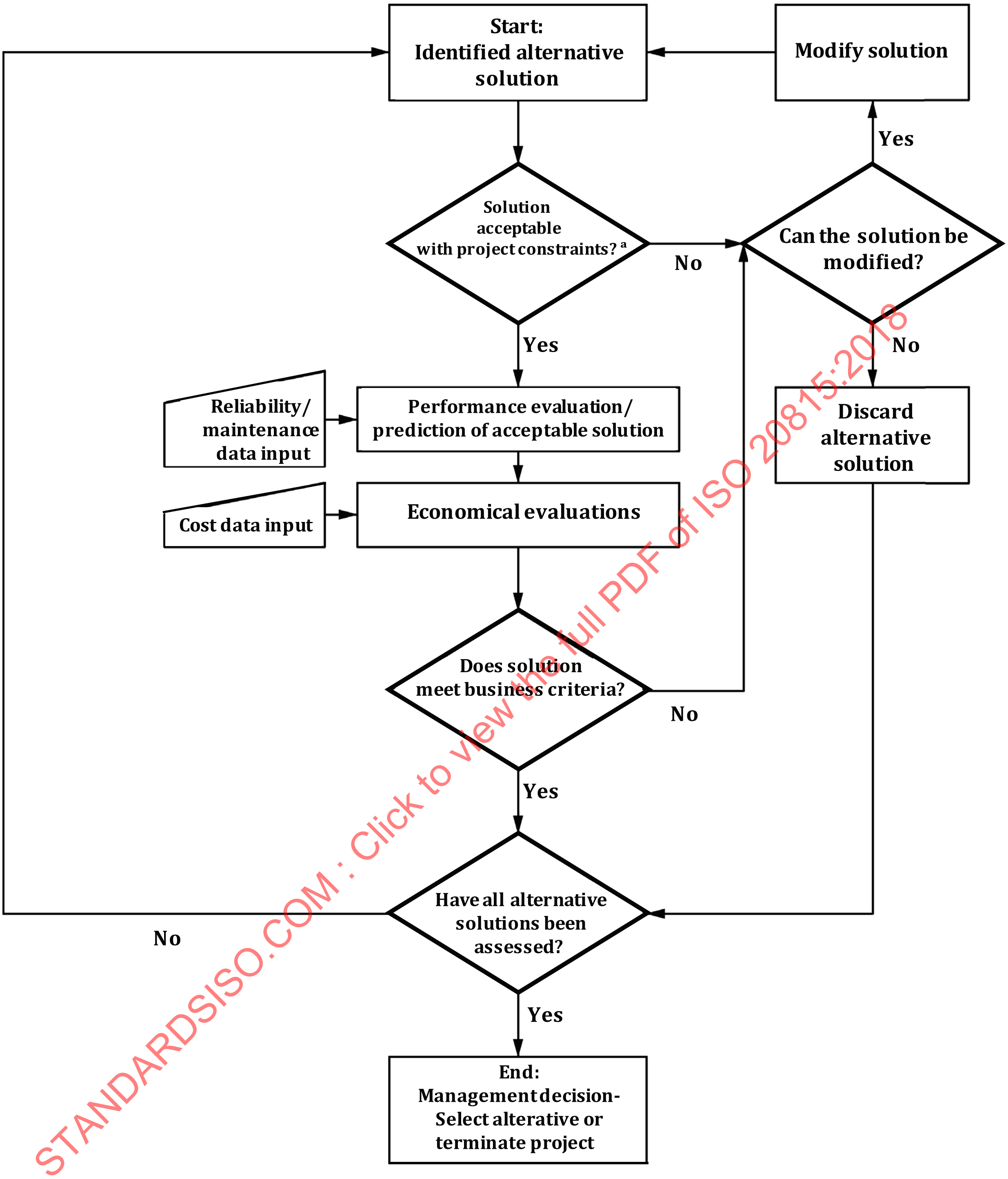
c) Predict the appropriate production assurance parameters.

d) Identify the preferred design solution based on an economical evaluation/analysis, such as net present value analysis or another optimization criterion.

e) Apply the optimization process as illustrated in Figure 3. Be aware that the execution of the optimization process requires that the production assurance and reliability function should be addressed by qualified team members.

f) If required, the process can be iterative, where the selected alternative is further refined and alternative solutions are identified. The iterative process is typical for “gated” or threshold project-execution phases.

g) Sensitivity analyses may be performed to take account of uncertainty in important input parameters.



a Typical project constraints include HSE requirements; technical feasibility; compliance with acts, rules and regulations; economical constraints; schedule constraints.

Figure 3 — Optimization framework

4.4 Production assurance programme

4.4.1 Objectives

A production assurance programme (PAP) shall serve as a management tool in the process of complying with this document. The PAP may be either established for the various life cycle phases of a new asset development project or established for assets already in operation. As production assurance is a continuous activity throughout all life cycle phases, it shall be updated as and when required. It can contain the following:

— systematic planning of production assurance work within the scope of the programme;

— definition of optimization criteria;

— definition of performance objectives and requirements, if any;

— description of the production assurance activities necessary to fulfil the objectives, how they are carried out, by whom and when;

— statements and considerations on interfaces of production assurance and reliability with other activities;

— methods for verification and validation;

— a level of detail that facilitates easy updating and overall coordination.

Annex A provides an index for the PAP contents.

Conformity to this document shall result in the establishment and execution of a PAP.

The life cycle phases indicated in Table 2 apply for a typical asset development project. If the phases in a specific project differ from the life cycle phases indicated in Table 2, the activities should be defined and applied as appropriate.

Major modifications may be considered as a project with phases similar to those of an asset development project. The requirements to production assurance activities as given for the relevant life cycle phases apply.

Similarly, research or technology development projects (that in short or long term can be implemented on an installation, e.g. oil/gas production facility, drilling facility, pipeline) should also benefit from use of the reliability management principles and methods as described in this document.

Likewise, life time extension projects for further development of existing installations (see Clause I.24), will also need to apply production assurance and reliability management.

4.4.2 Project risk categorization

It is necessary to define the level of effort to invest in a PAP to meet the business objectives for each life cycle phase. In practice, the production assurance effort required is closely related to the level of technical risk in a project. Therefore, it is recommended that one of the first tasks to be performed is an initial categorization of the technical risks in a project. This enables project managers to make a general assessment of the level of investment in reliability resources that may have to be made in a project.

The project risk categorization typically varies depending on a number of factors such as financial situation, risk attitude, etc. Hence, specific risk categorization schemes may be established. However, to provide some guidance on the process, a simple risk categorization scheme is outlined in this subclause.

Projects can be divided into three risk classes:

— high risk;

— medium risk;

— low risk.

The features that describe the three risk classes are further outlined in Table 1. Typically, there is a gradual transition from one risk class to another. Hence, a certain degree of subjective assessment is required. However, the justification for the selected risk class for a project should be included in the PAP issued during the feasibility or concept phase.

Table 1 — Project risk categorization

Technology	Operating envelope	Technical system scale and complexity	Organizational scale and complexity	Risk class[a]	Description
Mature technology	Typical operating conditions	Small scale, low complexity, minimal change of system configuration	Small and consistent organization, low complexity	Low	Low-budget, low-risk project using field-proven equipment in the same configuration and with the same team under operating condition similar to previous projects.
Mature technology	Typical operating conditions	Moderate scale and complexity	Small to medium organization, moderate complexity	Low or medium	Low- to moderate-risk project using field-proven equipment in an operating envelope similar to previous projects but with some system and organizational complexity.
Novel or non-mature technology for a new or extended operating environment	New, extended or aggressive operating environment	Large scale, high complexity	Large organization, high complexity	Medium or high[b]	Moderate- to high-risk project using either novel or non-mature equipment or with new or extended operating conditions. Project involves large, complex systems and management organizations.

[a] The term "low or medium" indicates that projects comprising the indicated features can be classified as either low-risk or medium-risk projects, likewise for the term "medium or high".

[b] The novel or non-mature technology should have a potential significant impact on the project outcome to be classified as high-risk.

The risk categorization should not be detached from the overall project's risk management process (see Clause C.2).

The project risk categorization (i.e. high, medium and low) is further applied in Table 2 to indicate what processes should be performed for the different project categories. The risk categorization from different users perspective can require different approaches, but the importance is that risk categorization should be in place in the user company to prioritize the production assurance activities.

4.4.3 Programme activities

Production assurance activities should be carried out in all phases of the life cycle of facilities to provide input to decisions regarding feasibility, concept, design, manufacturing, construction, installation, operation, maintenance and modification. Processes and activities shall be initiated only if they are considered to contribute to added value of the project.

The production assurance activities specified in the PAP shall be defined in view of the actual needs, available personnel resources, budget framework, interfaces, milestones and access to data and general information. This is necessary to reach a sound balance between the cost and benefit of the activity.

Production assurance should consider organizational and human factors as well as technical aspects (see Clause I.10).

Important tasks of production assurance are to monitor the overall performance level, manage reliability and the continuous identification of the need for production assurance activities. A further objective of production assurance is to contribute technical, operational or organizational recommendations.

The processes and activities specified in the PAP shall focus on the main technical risk items initially identified through a top-down screening process (see 4.4.2). A risk-classification activity can assist in identifying performance-critical systems that should be subject to more detailed analysis and follow-up.

The emphasis of the production assurance activities changes for the various life cycle phases. Early activities should focus on optimization of the overall configuration, while attention to critical detail increases in the later phases. The production assurance activities may also interact with integrity management activities.

Production assurance activities relate closely to the integrity management of the installations and system engineering activities, and the PAP should show such relationships.

In the feasibility and concept phases, the field layout configuration should be identified. This also includes defining the degree of redundancy (fault tolerance), overcapacity and flexibility, on a system level. This requires establishing the CAPEX, OPEX, LOSTREV, expected cost or benefit of risks and revenue for each alternative.

These financial values are, in turn, fed back into the operators' profitability tools, for evaluation of profitability and selection of the alternative that best fits with the attitude towards risk. Optimal production availability for field layouts requires that overemphasis on CAPEX is avoided, and it is recommended that this is achieved through long-term partnering between suppliers and operators, as well as between suppliers and their sub-suppliers. Such long-term relationships ensure mutual confidence and maturing of the technology. Early direct involvement of the above parties with focus on the overall revenue in a life cycle perspective is advised. This means, for example, implementing the resulting recommendations as specifications in the invitations to tender.

The production assurance principles outlined in this document require use of the reliability data methodology based on ISO 14224:2016, see the process "performance data tracking and analysis" (Process 9). See also guidance in Annex E. In addition, Annex G provides a framework for performance measures for production availability.

An overview of the production assurance processes is given in Table 2 and Clause 5, while descriptions of the recommended activities for the processes are given in Annex B and Annex C.

Table 2 provides recommendations (indicated by an "X") on which processes should be performed as a function of the project risk categorization (see 4.4.2). The table also provides recommendations (indicated by an "X") as to when the processes should be applied (in what life cycle phase). Production assurance requirements (process 1) can be used to illustrate the interpretation of the table. This process, which is further described in Annex B, should be implemented for medium- and high-risk projects, and performed in the feasibility, concept design, engineering and procurement life cycle phases.

Table 2 — Overview of production assurance processes versus risk levels and life cycle phases

Production assurance processes for asset development				Life cycle phase[e, f]						
Low-risk projects	Medium-risk projects	High-risk projects	Process name and number[c]	Feasibility	Conceptual design[a]	Engineering[b]	Procurement[g]	Fabrication/ Assembly/ Testing	Installation and commissioning	Operation
—	X	X	1. Production assurance requirements	X	X	X	X	—	—	—
X	X	X	2. Production assurance planning	X	X	X	X	X	X	X
—	X	X	3. Design and manufacture for production assurance	—	X	X	X	X	X	X
X	X	X	4. Production assurance	X	X	X	X	X	X	X
—	X	X	5. Risk and reliability analysis[d]	X	X	X	—	—	—	X
X	X	X	6. Verification and validation	X	X	X	—	—	—	—
X	X	X	7. Project risk management	X	X	X	X	X	X	X
—	—	X	8. Qualification and testing	—	X	X	X	X	—	—
X	X	X	9. Performance data tracking and analysis	—	—	—	—	X	X	X
—	—	X	10. Supply chain management	—	—	—	X	—	—	X
X	X	X	11. Management of change	—	X	X	X	X	X	X
X	X	X	12. Organizational learning	X	X	X	X	X	X	X

a Including front-end engineering and design (FEED).

b Including pre-engineering and detailed engineering.

c The following production assurance processes are within the main scope of work for this document: 1, 2, 3, 4, 5, 6 and 9.

d This process is primarily meant to cover production availability, system/equipment availability and component reliability analyses, but in this context may also include availability/reliability of safety systems, see B.5 and C.1. The relations to risk analysis are described in Annex H and Clause I.20. Annex D provides guidance for planning, execution and reporting of production performance analyses.

e Technology development projects can use similar production assurance processes.

f Lifetime extension projects can use similar production assurance processes. See Clause I.24.

g The procurement activities relate to various life cycle phases.

NOTE A process can be applicable for a certain risk class or life cycle phase although no "X" is indicated in this table. Likewise, if it can be argued that a certain process does not add value to a project, it can be omitted.

4.5 Alternative standards

There are a number of other international standards, industry standards, national standards and guidelines that support and direct the implementation of production assurance and reliability activities in projects.

Table 3 shows how the production assurance and reliability processes described within this document link to some other international standards. Work processes carried out in accordance with these international standards can be considered to satisfy the requirements for relevant processes in this document. The alternative standards listed in Table 3 are not normative for this document. The list of standards in Table 3 is non-exhaustive. Other standards can also cover specific requirements in this document. If alternative standards are referred to for compliance to specific requirements, it is the responsibility of the user to demonstrate such compliance.

Table 3 — Alternative international standards

International standard	1. Production assurance requirements	2. Production assurance planning	3. Design and manufacture for production assurance	4. Production assurance	5. Risk and reliability analysis	6. Verification and validation	7. Project risk management	8. Qualification and testing	9. Performance data tracking and analysis	10. Supply chain management	11. Management of change	12. Organizational learning
IEC 60300-1:2014	X	X	—	X	—	X	—	—	—	—	—	—
IEC 60300-3-2:2004	—	—	—	—	—	—	—	—	X	—	—	—
IEC 60300-3-4:2007	X	—	—	—	—	X	—	—	—	—	—	—
IEC 60300-3-14:2004	—	—	—	—	X	—	—	—	—	—	—	—
IEC 31010:2009	—	—	—	—	X	—	X	—	—	—	—	—

5 Production assurance processes and activities

The production assurance processes defined in this document are divided into two main classes, i.e. core processes and interacting processes. The main reason for this split is to indicate for which processes a potential production assurance discipline is normally responsible and for which processes other disciplines (e.g. project management, QA, etc.) are normally responsible. However, all processes can be equally important to ensure success.

Annex B provides recommendations for the core production assurance processes and activities that may be carried out as part of a PAP in the various life cycle phases of a typical asset development project.

Projects other than asset developments, e.g. drilling units, transportation networks, major modifications, etc., have phases that more or less coincide with those described in the following. The activities carried out can, however, differ from those described.

Hence, the PAP may be adapted for each part involved to ensure that it fulfils the business needs.

In addition to the core production assurance processes and activities described in Annex B, a number of interacting processes are described in Annex C. These processes are normally outside the responsibility of the production assurance discipline, but information flow to and from these processes is required to ensure that production performance and reliability requirements can be fulfilled.

Figure 4 illustrates which processes are defined as core production assurance processes and which are considered interacting processes. Details regarding objectives, input, output and activities for each of the processes are further described in Annexes B and C.

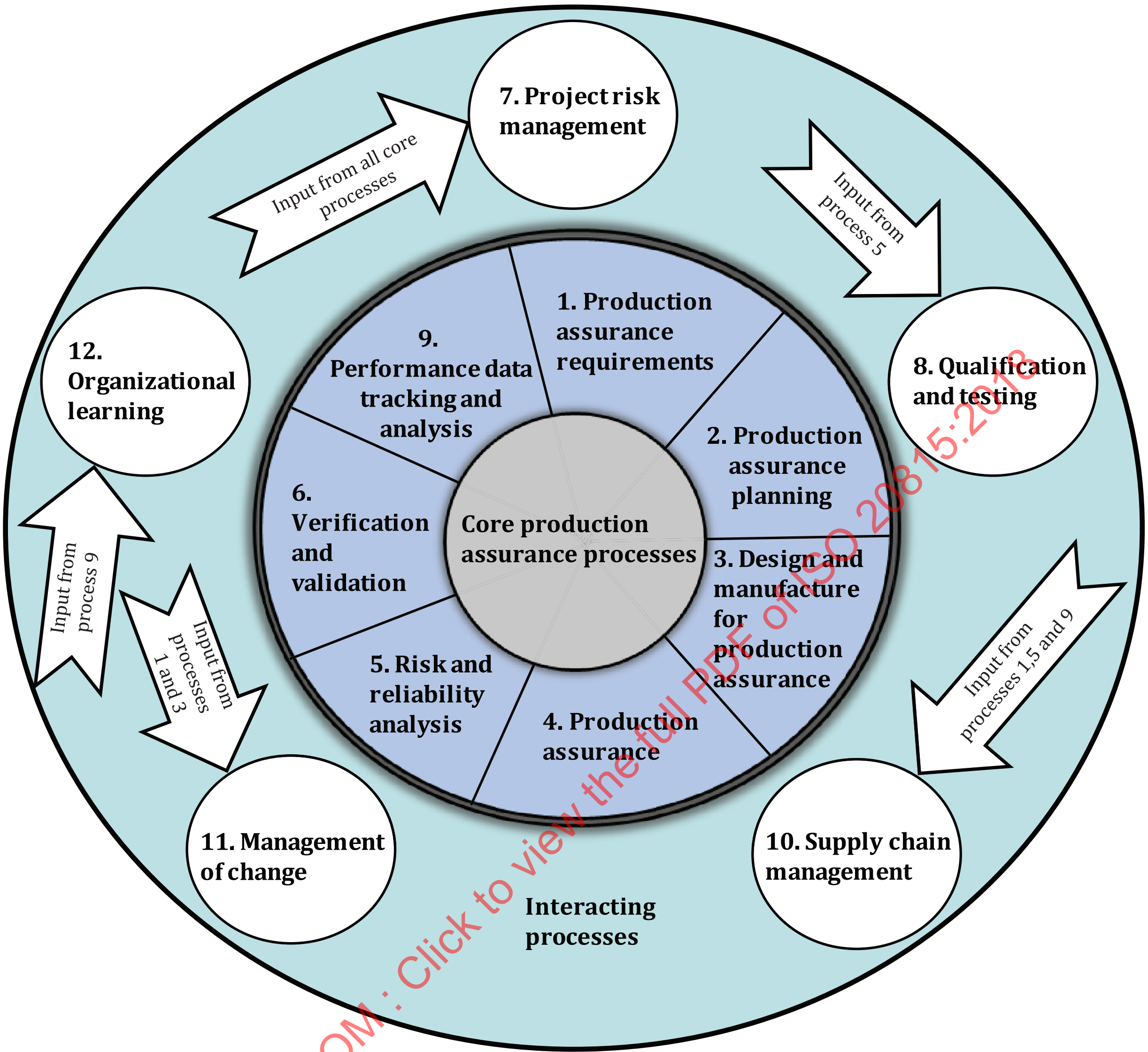


Figure 4 — Core and interacting production assurance processes

Annex A
(informative)

Contents of production assurance programme (PAP)

A.1 General

This document describes the concept of production assurance (see Clause 4) and provides processes and activities that culminate in a production assurance programme (PAP) (see 4.4.1). This annex suggests a model for that PAP. A PAP (see 4.4) should cover the topics covered in Clauses A.2 to A.8.

The PAP is generally used for the entire asset or project by the operator, but can also apply for the engineering contractor or a supplier/manufacturer for their scope of work in a project. The latter may then be named "reliability management programme" (RMP), but entails the same guidance as described in this annex. It may also apply for a technology development project for an operator or supplier, or in a product portfolio (e.g. specific equipment categories or equipment classes; see ISO 14224:2016) to ensure reliability management.

A.2 Title

Production assurance programme (PAP) for [insert the description of the project].

A.3 Terms of reference

A general description of the PAP similar to the following may be given:

a) purpose and scope;

b) system boundaries and life cycle status;

c) revision control showing major changes since last update;

d) distribution list which, depending on the content, shows which parties receive all or parts of the PAP.

A.4 Production assurance philosophy and performance objectives

A description of the philosophy and performance objectives similar to the following may be given:

a) description of overall optimization criteria (see 4.3);

b) definition of performance objectives and requirements (see Annex F) with references to performance targets, objectives and requirements in contract documents and any separate documents that may further specify the targets, objectives and requirements, e.g. loss categories and battery limits to define what is included and what is excluded in the targets;

c) definition of performance measures.

A.5 Project risk categorization

A description of the project risk categorization (see 4.4.2) should be included in the PAP to justify the selection of production assurance programme activities.

A.6 Organization and responsibilities

A description of the production assurance organization with corresponding authorities and responsibilities should be clearly stated in the PAP. Descriptions similar to the following may be given:

a) description of the organization and responsibilities, focusing on production performance, internal and external communication, responsibilities given to managers and key personnel, functions, disciplines, sub-projects, contractors and suppliers;

b) description of the action management system, defining how the production assurance activities recommendations and actions are communicated, evaluated and implemented;

c) description of the verification and validation functions specifying planned third-party verification activities related to production assurance/reliability (if any).

A.7 Activity schedule

A description of the activity schedules similar to the following may be given:

a) overview of the production assurance activities during life cycle phases, which may contain a table similar to Table 2 to indicate past and future production assurance activities;

b) list of the plans or references to other documents containing the plans for production assurance/reliability activities showing the main project milestones and interfacing activities;

c) clear statements of the relationship between the various production assurance activities, e.g. input/output relationship and timing.

A.8 References

References are made to, and revised as appropriate when updating the PAP:

— key project documentation;

— relevant corporate or company requirements;

— relevant international, industry or national standards;

— list of production assurance deliverables (documentation).

Annex B
(informative)

Core production assurance processes and activities

B.1 Production assurance requirements — Process 1

This process is administrative by nature and supports the economical optimization process (see 4.3) aiming at formulating production assurance requirements. The main activity for this process is related to communication among relevant parties. Production assurance process 1 is described in Table B.1.

Unnecessary limitations in the form of unfounded performance requirements should be avoided to prevent otherwise favourable alternatives from being rejected during the optimization process.

Optimal production availability in the oil and gas business requires a standardized, integrated reliability approach, as this clause provides for asset development. This is an economic optimization problem, with defined framework conditions and constraints. This optimization problem involves both production assurance and interfacing processes.

The constraints from other disciplines as outlined in Figure 3 should be considered together with relevant performance measures (see Annex G) in the optimization process.

In the feasibility and concept phases, the asset configuration should be identified. This also includes the degree of redundancy (fault tolerance), overcapacity and flexibility, on a system level. This requires establishing the CAPEX, OPEX, LOSTREV, expected cost or benefit of risks and revenue for each alternative. These financial values are, in turn, fed back into the operator's profitability tools, for evaluation of economic viability and selection of the alternative that best fits with the attitude towards risk. Optimal production availability for field layouts requires that overemphasis on CAPEX should be avoided, and it is recommended that this is achieved through long-term partnering between suppliers and operators, as well as between suppliers and their sub-suppliers. Such long-term relationships ensure mutual confidence and maturing of the technology together. Early, direct intervention of the above parties with focus on the overall revenue in a life cycle perspective is advised. This means, for example, implementing the resulting recommendations as specifications in tender documents.

Specification of performance objectives and requirements are further described in Annex F.

Table B.1 — Production assurance requirements — Process 1

Process elements	Life cycle phase(s)			
	Feasibility	**Conceptual design**	**Engineering**	**Procurement**
Objective	Provide tentative production assurance requirements for various asset development options	Provide production assurance requirements for the selected asset development option(s)	Allocate the production assurance requirements from the concept phase to the subsystems, as required	Ensure that the relevant manufacturers at each level of the supply chain understand what reliability is required, and with which reliability standards to comply
Input	Alternative asset development plans	The selected asset development plan, with the estimated production availability formulated as a system requirement in the invitation to tender alternative field layout configurations Production availability analysis	Output from the concept phase	Output from the engineering phase
Production assurance activities	Identify additional constraints Initiate estimation of the production availability for the asset development options specified as input on a system level Planning, reporting and follow-up for the requirements	Initiate estimation of the production availability for the asset development options These estimates are aggregated from each main supplier's scope of supply, as defined by the asset development Planning, reporting and follow-up for the requirements	Define and allocate the production assurance requirements to the subsystems, as required This definition is based on the production availability analysis Planning, reporting and follow-up for the requirements	Ensure that the reliability requirements are included in the tender documents, through interfacing with the procurement organization Planning, reporting and follow-up for the requirements
Output	Production availability estimates for the asset development options specified as input Estimated production availability for each option, formulated as a system requirement for the option to be selected Other relevant qualitative or quantitative production assurance requirements	Production availability estimates for the asset development options specified as input, allocated according to each main supplier's scope of supply Other relevant qualitative or quantitative production assurance requirements	Subsystem production availability requirements for the selected option, as required This includes the applied subsystem reliability data Other relevant qualitative or quantitative production assurance requirements	Subsystem reliability requirements, including with which reliability standards to comply Other relevant qualitative or quantitative production assurance requirements

B.2 Production assurance planning — Process 2

This process is relevant for all life cycle phases and relates to planning and management of the production assurance process. The PAP represents the main production assurance management tool.

An overall PAP for an asset may be considered to coordinate or replace separate project PAPs on lower levels.

Further requirements for the PAP are described in 4.4 and in Annex A. Production assurance process 2 is described in Table B.2.

Table B.2 — Production assurance planning — Process 2

Process elements	Life cycle phase(s) All
Objective	To establish and maintain a PAP (see 4.4) to ensure that the production assurance requirements are fulfilled
Input	Project plans, which are required to schedule the production assurance activities before decisions are made and after the required information is established Project risk categorization Output from process 1 — Production assurance requirements Output from process 3 — Design and manufacture for production assurance Output from process 5 — Risk and reliability analysis
Production assurance activities	A PAP should be established and updated for asset development projects. The required contents of the PAP are the production assurance performance objectives, organization and responsibilities and activity schedules (see Annex A). The core of the production assurance programme defines the activities required to comply with the constraints (see Figure 4) and the production assurance requirements (see Clause B.1). I.e. this activity requires scheduling of the tabulated production assurance activities for the relevant risk level and project phase. The production assurance activities should be performed in a timely manner in order to support decisions before they are made The extent of the production assurance programme (i.e. amount of planned activity) should be based on the project risk categorization as described in 4.4.2. This means that an asset development project defined as high or medium risk normally is comprised of more production assurance activities than a low-risk project
Output	Initial PAP Updated PAP for later life cycle phases, including the following: — status and reference to documentation for the scheduled PAP activities; — documentation of the fulfilment of the production assurance requirements (alternatively, references to evidence); — reference to the risk register (see Clause C.2); all mitigating actions arising from the production assurance programme should be transferred to the risk register for follow-up and close-out. Input to process 4 — Production assurance NOTE A close-out report for production assurance activities upon completion of a project can be useful, also in organizational learning (see Process 12).

B.3 Design and manufacture for production assurance — Process 3

Systematic identification of potential opportunities for reliability improvement and reduction of technical and operational risks should be performed during all life cycle phases, except the feasibility where this process is considered less relevant.

Identification of improvement potentials should be based on observed in-service performance data (feedback loop, see Figure B.1; see also ISO 14224:2016, Figure 1) and information gathered from production performance analyses. Improvements can also be made by new technology and associated technology qualification (see Process 8).

Cost-efficient decisions on what improvements to implement require a good understanding of what causes business impact (production, operation and HSE).

Production assurance process 3 is about implementing improvements ("feed forward loop") during design, manufacture, test and installation and operational phases to drive production assurance, and is described in Table B.3. See also Figure B.1.

Table B.3 — Design and manufacture for production assurance — Process 3

Process elements	Life cycle phase(s) All (except feasibility)
Objectives	Identify the need for improved system reliability performance or reduced risk in a project to ensure that performance requirements are not compromised Based on tracking and analysis of performance data, identify and communicate potentials for improved equipment or system reliability or risk reduction to the system or equipment manufacturers Implement improvements ("feed forward loop") during design, manufacture, test and installation and operational phases to meet production assurance objectives and requirements
Inputs	Output from process 1: Production assurance requirements Output from process 5: Risk and reliability analysis (reliability analysis, production availability and risk identification results) Output from process 9: Performance data tracking and analysis
Production assurance activities	The specific production assurance and reliability management activities related to this process are performed within other processes. Communication of the potential reliability improvement or risk-reduction requirements or proposals to the right recipient Decide production assurance improvements to be implemented by project
Output	Reliability improvement or risk reduction proposals Input to process 2: Production assurance planning Input to process 11: Management of change

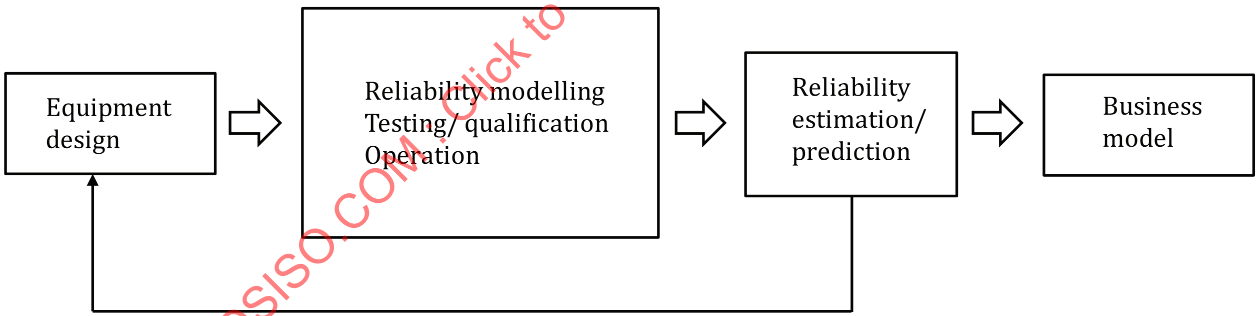


Figure B.1 — Typical feedback (estimation) for reliability improvement in design and manufacture and feed forward loop (prediction) for actual performance (business model)

B.4 Production assurance — Process 4

This process is relevant for all life cycle phases and relates to the management, follow-up and documentation of the production assurance process and demonstration that the production performance requirements are adhered to. Production assurance process 4 is described in Table B.4.

Table B.4 — Production assurance — Process 4

Process elements	Life cycle phase(s) All
Objective	Reporting and follow-up of the production assurance activities to manage and demonstrate the production assurance process
Input	Output from process 1: Production assurance requirements Output from process 2: Production assurance planning Output from the production assurance activities (see below)
Production assurance activities	Reliability assurance (management and demonstration) is comprised of reporting and follow-up of the production assurance activities and should be performed for all the project phases Follow-up of the production assurance process: A follow-up system for production assurance should be applied to ensure progress of the PAP activities and the resulting actions that are transferred to a risk register. A risk register or a similar document should be used as a production assurance demonstration document
Output	Production assurance demonstration document, which contains evidence that the production assurance requirements are fulfilled Input to process 7 — Project risk management

B.5 Risk and reliability analysis — Process 5

This process covers the actual performance of the production performance analysis, i.e. risk and reliability analyses. Production assurance process 5 is described in Table B.5.

It is necessary that optimal technical safety and reliability are designed into new projects and integrated into the design process through all the design phases. In traditional design processes, technical safety and reliability aspects are generally not considered until some verification of equipment or components is required. This is usually too late in the system design process to obtain an optimal design. Hence, early design for reliability is necessary to support the project development.

The objective is to define a process that can be used to integrate reliability considerations into the design process, thus representing a pro-active approach.

The feasibility- and concept-phase reliability activities should focus on the optimization of the overall configuration and identification of the critical subsystems, while attention to the details of critical subsystems increases in the engineering phase.

Table B.5 — Risk and reliability analysis — Process 5

Process elements	Life cycle phase(s)			
	Feasibility	**Conceptual design**	**Engineering**	**Operation**
Objectives	To provide partial decision support for selecting an asset development plan, e.g. — topside or subsea solution — capacity, pressure rating and pumping requirements for a pipeline system — process plant development solution	To provide partial decision support for selecting an asset configuration, e.g. — number and type of wells and manifolds; — number of pumps in a pumping station — number of compressors in a process plant	To provide partial detailed design decision support	To measure actual performance against that predicted in preceding phases Or also undertaking any analysis on subject matters important during this life cycle phase
Inputs	Alternative asset development plans Output from process 2: Production assurance planning	Selected asset development plan, with the estimated production availability formulated as a system requirement in the invitation to tender Alternative field layout configurations Output from process 4: Production assurance	Selected field layout configuration Alternative design solutions, as they arise in the design process Output from process 4: Production assurance	As-built information Detailed recording of system performance parameters Output from process 4: Production assurance
Production assurance activities	The purpose of production availability analysis in this phase is to contribute to optimizing the asset development plan. The production availability for alternative asset development plans should be established. The parameters below are guidance to establish:	The purpose of production availability analysis in this phase is to contribute to optimizing the field layout configuration. The production availability for 2 or 3 alternative layout-configuration options should be established. Identify such options by varying the parameters below:	The purpose of production availability analysis in this phase is mainly to verify compliance with requirements, since most of the decisions influencing the requirements have already been made. However, recommendations for spare parts should be established.	The purpose of production availability analysis in this phase is to determine if the operating asset is meeting the predicted production availability, and where necessary provide transparent insight to sources of degraded performance Interaction also with reliability-centred maintenance (see Clause I.14). Use of production performance analysis support in field modification projects (e.g. life time extension, new tie-in projects; see Clause I.24).

Table B.5 *(continued)*

Process elements	Life cycle phase(s)			
	Feasibility	**Conceptual design**	**Engineering**	**Operation**
	— fault tolerance, i.e. redundancy; — proven versus novel solutions; — flexibility, e.g. possibility for alternative routings, reconfigurations and future expansions; — maintainability, e.g. minimizing the amount of down time required for maintenance.	— fault tolerance, i.e. redundancy; — proven versus novel solutions; — simplicity, e.g. minimizing the number of required connections, which are potential sources of failures; — overcapacity, e.g. partial or complete fulfilment of the design intent of the system in a degraded mode of operation; — flexibility, e.g. the possibility for alternative routings, reconfigurations and future expansions; — maintainability, e.g. minimizing the amount of down time required for maintenance.		A reliability analysis technique may be selected (see Annex I)
	The purpose of the equipment reliability analysis is to screen the delivery project to identify the critical parts, which are then studied in more detail to identify possible improvements. A reliability analysis technique may be selected (see Annex I)	The purpose of the equipment reliability analysis is to screen the delivery project to identify the critical parts, which are then studied in more detail to identify possible improvements. A reliability analysis technique may be selected (see Annex I)	The purpose of the equipment reliability analysis is to screen the delivery project to identify the critical parts, which are then studied in more detail to identify possible improvements. A reliability analysis technique may be selected (see Annex I)	

Table B.5 *(continued)*

Process elements	Life cycle phase(s)			
	Feasibility	Conceptual design	Engineering	Operation
Output	Production availability estimates for the options specified as input Identified risks (for transfer to the risk register; see Clause C.2)	Production availability estimates for the options specified as input Identified risks (for transfer to the risk register; see Clause C.2)	Production availability estimates for the options specified as input. Identified risks (for transfer to the risk register; see Clause C.2)	Tracking and reporting of operational production availability against predicted performance. Identified or predicted risks (for transfer to the risk register; see Clause C.2)

B.6 Verification and validation — Process 6

The main objective of this process is to ensure that the implemented solution is in compliance with the requirements in the production assurance programme. The production assurance verification and validation process has an important interface with the design review and other technical verification activities in the sense that the production assurance aspects should be addressed in the review. However, the design review process itself is normally the responsibility of engineering departments. Production assurance process 6 is described in Table B.6.

Table B.6 — Verification and validation — Process 6

Process elements	Life cycle phase(s) Feasibility, conceptual design and engineering[a]
Objective	To ensure that the implemented production performance is in compliance with the requirements in the PAP
Input	Output from process 4: Production assurance Output from process 7: Project risk management
Production assurance activities	The production assurance verification process comprises document control and design review. The essence of the document control is to check that the assumptions, selected methods, input data, results and recommendations are reasonable The production assurance validation process comprises a final check of the predicted/ implemented production performance versus the requirements in the PAP. The essence of the validation is to check that all the activities scheduled in the PAP are completed and that all entries in the risk register are closed out Compliance with the ISO 9000 series is regarded as an alternative fulfilment of the verification and validation process
Output	PAP updates including reference to the closed-out activities and actions in the risk register

a Installation, commissioning and operation are covered in process 9 (see Clause B.7).

B.7 Performance data tracking and analysis — Process 9

This process covers the complementary parts of process 6 (Verification and validation) in the sense that it represents the ‘verification’ and ‘validation’ of the production performance during installation, commissioning and operation. Production assurance process 9 is described in Table B.7.

Table B.7 — Performance data tracking and analysis: Process 9

Process elements	Life cycle phase(s)	
	Installation and commissioning	**Operation**
Objective	Prepare for collection and analysis of performance data	Collect and analyse operational performance data to identify possible improvement potentials and to improve the data basis for future production assurance and reliability management activities
Input	System descriptions from the engineering phase	Inventory models Performance records (e.g. from maintenance management systems)
Production assurance activities	Prior to the operation phase, equipment inventory models should be established to enable the start of performance tracking (data collection) and analysis. Reference is made to ISO 14224:2016 for performance data tracking and analysis recommendations Furthermore, collection of performance data relating to the installation process itself should be considered to identify potentials for future installation performance improvements	During operation, performance data should be collected continuously or at predetermined intervals. Analysis of the collected data should be undertaken regularly to identify reliability improvement and risk reduction potentials
Output	Inventory models Installation performance data	Operational performance data Input to process 3: Design and manufacture for production assurance Input to process 10: Supply chain management Input to process 12: Organizational learning

Failures occurring on equipment during fabrication and detected during acceptance testing (e.g. FAT, SAT and SIT) is also important to assess, see also ISO 14224:2016, 5.2.

Production assurance activities (e.g. production performance analysis) can reveal the need for reliability data that can require data collection in accordance with ISO 14224:2016.

Collection and analysis of performance data is further described in Annex E. Furthermore, Annex G provides examples of performance measures that can be tracked and analysed.

NOTE Data qualification is part of process 5: Risk and reliability analysis.

Annex C
(informative)

Interacting production assurance processes and activities

C.1 General

The interacting processes described in this annex are not included in the responsibility of the production assurance discipline. However, these interacting processes are required in order to achieve the required production performance.

C.2 Project risk management — Process 7

All mitigating actions arising from the production assurance programme should be linked to or transferred to the risk register for follow up and close out, in order to have only one register for all kinds of risks. This transferral is the responsibility of the production assurance discipline. See also ISO 31000:2018 and ISO 17776:2016.

The risk register and the PAP are information carriers and decision tools with regards to risk.

Interacting process 7 is described in Table C.1.

Table C.1 — Project risk management — Process 7

Process elements	Life cycle phase(s) All
Objective	The objective of project risk management is to ensure that all risk elements capable of jeopardizing the successful execution and completion of a project are identified and controlled/mitigated in a timely manner
Input	Transferred action items from all the production assurance processes
Production assurance activities	Follow-up and close-out of all actions transferred from the production assurance processes
Output	Risk register

C.3 Qualification and testing — Process 8

The objective of this testing versus production assurance is to ensure that adequate functionality and acceptable robustness against dominating failure modes for critical technology items is demonstrated through the qualification test program.

Interacting process 8 is described in Table C.2. This process addresses qualification and testing where typically a technology qualification programme (TQP) has been established (see DNVGL-RP-A203:2017 and API RP 17N:2017), but some of the principles can apply for fabrication and assembly testing (e.g. FAT and SAT) for other equipment deliveries not subject to technology qualification.

The validation of proven technology (TRL 7, ref. Table I.8 in Clause I.21) will also use operating experience as achieved in Process 9, and associated reliability data as defined in ISO 14224:2016.

Table C.2 — Qualification and testing — Process 8

Process elements	Life cycle phase(s)		
	Conceptual design	**Engineering**	**Procurement and fabrication/assembly/testing**
Objective	Identify the technology items requiring qualification testing	Ensure that acceptable robustness against dominating failure modes for critical technology items is demonstrated through the qualification test program	Ensure that acceptable robustness against dominating failure modes for critical technology items is demonstrated through the qualification test program
Input	Scope of supply Design basis	Output from process 5: Output from equipment reliability analysis Output from production availability analysis The reliability processes should identify the relevant failure modes[a] for the technology items tested and communicate this to the engineering organization that is responsible for establishing the test program through the risk register	Output from process 5: Output from equipment reliability analysis. Output from production availability analysis. The reliability processes should identify the relevant failure modes[a] for the technology items to be tested and communicate this to the engineering organization through the risk register, which is responsible for establishing the test program
Production assurance activities	Identifying the technology items requiring qualification testing by technology novelty scoring (see Table I.8 in Clause I.21)	Establish qualification procedures Perform testing Establish qualification test reports	Establish qualification procedures Perform testing Establish qualification test reports
Output	List of technology items requiring qualification testing	The engineering organization should communicate the test results regarding the relevant failure modes to the production assurance discipline. The reliability value by new qualified technology should also be part of qualification testing reporting	The engineering organization should communicate the test results regarding the relevant failure modes to the production assurance discipline. The operational preparedness for use of new qualified technology should also be part of qualification testing documentation

[a] The evaluation of relevant failure modes should also consider operational experience of similar components in addition to the lab/qualification test results in order to catch possible failure events that are more closely associated with some particular operational conditions and/or procedures and, normally, not revealed by lab tests.

Reliability testing techniques are used in qualification testing and various techniques (e.g. accelerated life testing) are further described in Clause I.9.

C.4 Supply chain management — Process 10

The main purpose of this interacting process is to ensure that manufacturers at each level of the supply chain are aware of and understand the specified reliability requirements and take appropriate actions to increase the probability that the specified requirements can be achieved.

Interacting process 10 is described in Table C.3.

Table C.3 — Supply chain management — Process 10

Process elements	Life cycle phase(s)	
	Procurement	**Operation**
Objective	Ensure that manufacturers at each level of the supply chain understand the reliability requirements and take appropriate actions to increase the probability that the specified requirements can be achieved	Analyse collected data regularly to identify reliability improvement potential. Ensure that manufacturers take appropriate actions to increase the probability that the improvements can be achieved.
Input	Output from process 1: Production assurance requirements (with respect to equipment design and equipment delivery) Output from process 5: Risk and reliability analysis Output from process 9: Performance data tracking and analysis	Output from process 1: Production assurance requirements (with respect to evaluating/ monitoring equipment performance) Output from process 5: Risk and reliability analysis Output from process 9: Performance data tracking and analysis
Production assurance activities	Ensure that reliability requirements are addressed in the supply chain	Ensure that reliability requirements are addressed in the supply chain
Output	Distributed reliability requirements for the supply chain	Distributed reliability requirements for the supply chain Information for spare parts evaluation

C.5 Management of change — Process 11

The engineering discipline is responsible for technical changes.

The objective of the management of change process versus the production assurance is to ensure that no changes compromise the production assurance requirements. The consequence of this is that a risk assessment versus the production assurance is required.

The impact of changes should be qualitatively assessed as part of project risk management to determine the level of effort required to analyse the impact. The outcome of this assessment can typically be

— no activities, for changes with minor risk impact versus the production assurance;

— design review, for changes with medium risk impact versus the production assurance;

— equipment reliability and/or production availability analysis, for changes with a high risk impact versus the production assurance.

The assessment of the impact on the production assurance from the changes should normally be an integrated part of the design review. Hence, the design review form should include a production assurance checkpoint (e.g. the impact on production availability from the change).

However, if the risk of compromising the production assurance is deemed high, the equipment reliability and/or production availability analysis should be updated/initiated.

Interacting process 11 is described in Table C.4.

Table C.4 — Management of change — Process 11

Process elements	Life cycle phase(s) All (except feasibility)
Objective	To ensure that no changes compromise the production assurance requirements
Input	Output from process 1: Production assurance requirements Output from process 3: Design and manufacture for production assurance Description of the change
Production assurance activities	Assess production assurance impacts from changes, e.g. during design reviews
Output	Input to process 7: Input to or update of the risk register Performance impact assessments resulting from changes Initiation of the equipment reliability and/or production availability analysis

C.6 Organizational learning — Process 12

The purpose of the interacting process "organization learning" in a production assurance perspective is to communicate positive and negative experiences related to reliability and production performance from previous asset development projects to reduce the likelihood that product and process failures of the past are repeated. The process is considered relevant for all life cycle phases.

Lessons learned can include human factors issues; see I.10. The production assurance process will demonstrate that these lessons are considered in new designs, modifications and in revisions to existing processes and procedures.

EXAMPLE If one builds a gym on top of the sleeping area in the accommodation and the sound is transmitted through the floor, people could be kept awake by those on the other shift using the gym. This increases the possibility of fatigue, a negative performance shaping factor. This problem can be brought to light by complaints. Use the feedback to avoid this problem in subsequent designs.

Interacting process 12 is described in Table C.5.

Table C.5 — Organizational learning — Process 12

Process elements	Life cycle phase(s) All
Objective	To ensure that product and process failures of the past is not repeated
Input	Lessons learnt during previous projects Output from process 9: Performance data tracking and analysis
Production assurance activities	The responsibility of the production assurance and reliability management function in projects is to participate in reviews of lessons learnt and other relevant experience transfer Furthermore, relevant lessons learnt in one project should be transferred into future projects
Output	Lessons learned (positive and negative) Risk register

Annex D
(informative)

Production performance analyses

D.1 General

Production performance analyses should be planned, executed, used and updated in a controlled and organized manner.

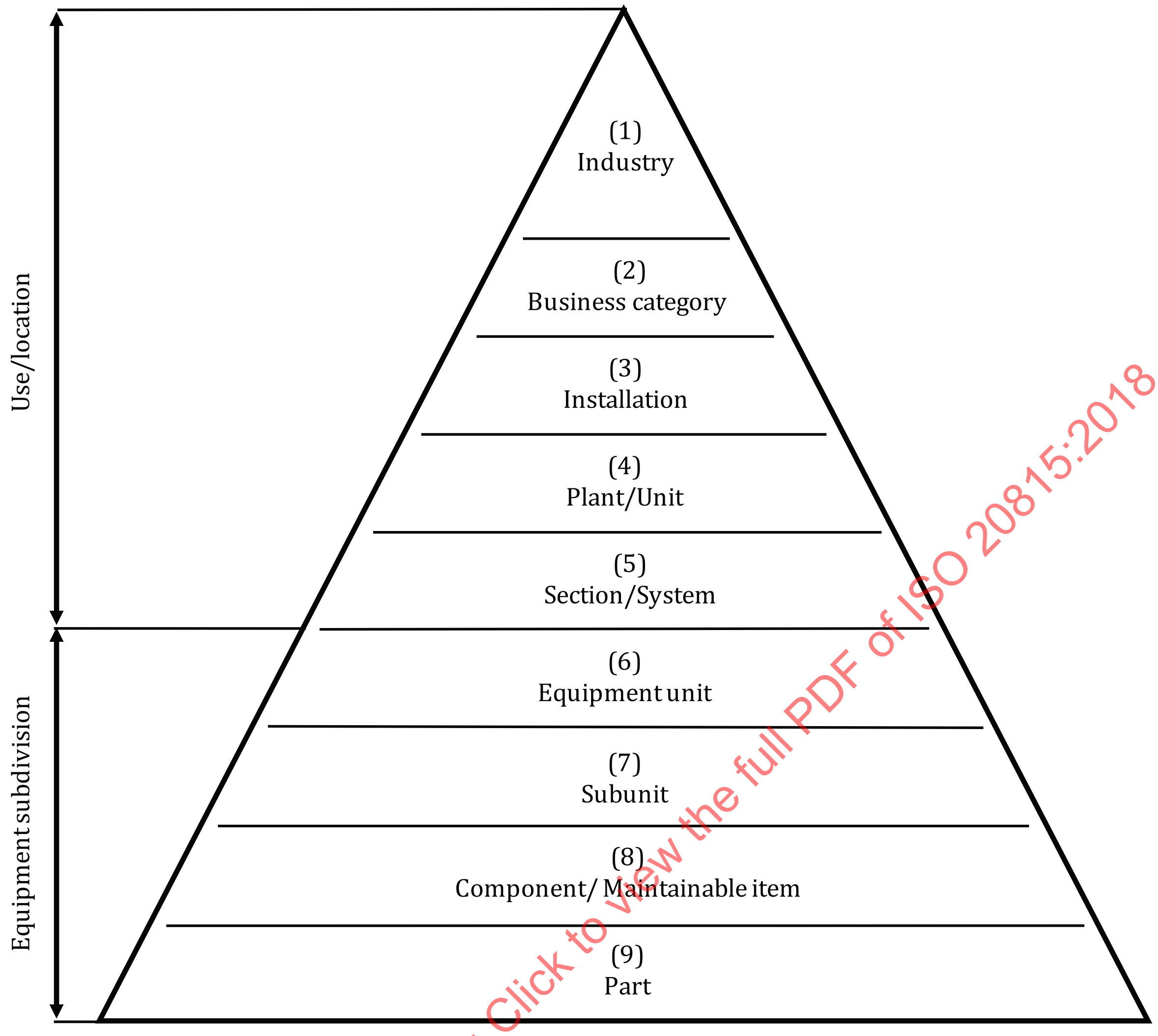
Production performance analyses should provide a basis for decisions concerning the choice of solutions and measures to achieve an optimum economy within the given constraints. This implies that the analysis should be performed at a point in time when sufficient details are available to provide sustainable results. However, results should be presented in time for input to the decision process.

Production performance analyses should be consistent and assumptions and reliability data traceable.

Suitable analysis tools, calculation models, data and computer codes that are acceptable to the involved parties should be chosen. Be aware that analysis tools and calculation models are under constant development.

Recommendations given in this annex apply to the production performance analyses of complete installations, but can also apply to reliability and availability analyses of components/systems with obvious modifications.

Reporting of production performance analysis results should be at the relevant taxonomy level as outlined in the Figure D.1. Production availability for entire production facility is typically reported at taxonomic levels 3 - 4, whilst production unavailability can be reported to reflect production loss impact from items on underlying taxonomic levels 5-9 when the analysis has a smaller scale focus. See further description in this annex.



NOTE This is a reproduction of ISO 14224:2016, Figure 3.

Figure D.1 — Taxonomy classification with taxonomic levels

Figure D.2 illustrates the framework for this document. Collection of equipment reliability and maintenance data is an important basis for production performance analysis. This topic is addressed in ISO 14224:2016. These data are further treated and analysed to establish failure rates, repair time, etc., typically on equipment, subunit or component level (taxonomy levels 6 - 8, see Figure D.1). Smaller scale availability assessments may be done at equipment level, e.g. as a function of component reliability and maintainability. In this case, only (time-based) availability is assessed without considering the (volumetric) production. It is also common to perform such availability analyses at system, plant or installation level (taxonomy levels 3 - 5, see Figure D.1). If production volume is not considered, such analyses may be performed with traditional reliability block diagrams (RBD) or fault tree analyses (FTA). More information about these techniques is included in Clauses I.3 and I.4. ISO/TR 12489:2013 addresses reliability modelling and calculation of safety systems also applicable for non-safety systems, but does generally not focus on production assurance.

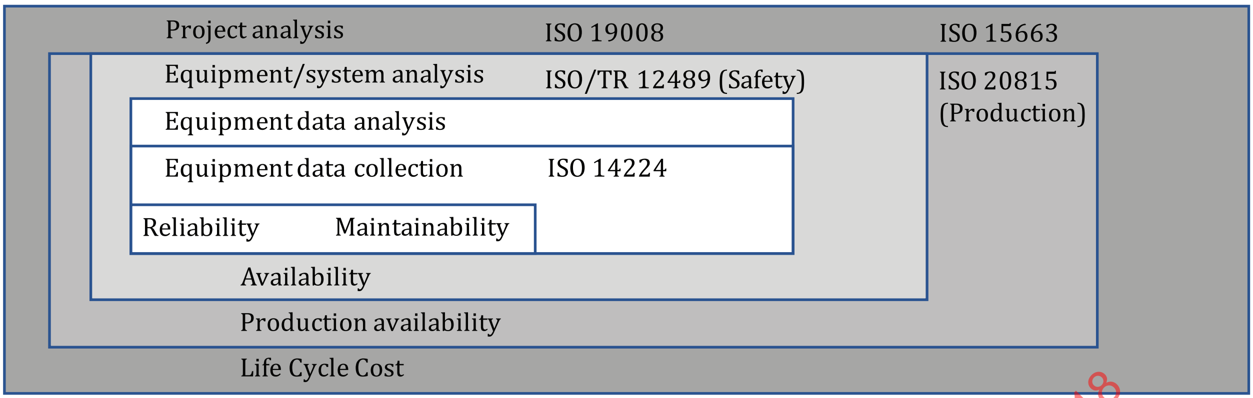


Figure D.2 — Illustration of different analyses on various taxonomy levels

Production forecasting or production availability analyses are typically assessments of plant/unit or installation performance (taxonomy levels 3 and 4, see Figure D.1), as a function of equipment reliability performance of smaller units like equipment or components (taxonomy levels 6 - 8, see Figure D.1).

For production systems, it is important to consider the production itself combined with the equipment availability. The consequences of equipment unavailability depend on factors such as capacity, production profiles, demands and buffers, setting the availability into the context of production performance. This is the primary focus of this document. The term "production" in this case is used in the broadest sense, and could cover e.g. drilling, workover and intervention activities, as well as the actual oil/gas production or gas/water injection. As Figure D.2 illustrates, it should also be noted that production performance can be put in a larger context where the complete economy of the production life is considered through life cycle cost (LCC) analysis. Thus, analyses performed according to this document give valuable input to LCC, which is covered in the ISO 15663:2001 (all parts) and ISO 19008:2016. See also Figure 2.

D.2 Planning

D.2.1 Objectives

The objectives of the analyses should be clearly stated prior to any analysis. Preferably, objectives can be stated in a production assurance activity plan as a part of the PAP structure. Objectives can be to:

— verify production assurance objectives or requirements;

— identify operational conditions or equipment units critical to production assurance;

— predict production availability, deliverability, availability, reliability, etc.;

— identify technical and operational measures for performance improvement;

— compare alternatives with respect to different production assurance aspects;

— enable selection of facilities, systems, equipment, configuration and capacities based on economic optimization assessments;

— provide input to other activities, such as risk analyses or maintenance and spare-parts planning.

D.2.2 Production performance analysis information

The system for analysis should be defined, with necessary boundaries relative to its surroundings. An analysis of a complete production chain can cover reservoir delivery, wells, process and utilities, product storage, re-injection, export and tanker off-take.

Operating modes for inclusion in the analysis should be defined. Examples of relevant operating modes are start-up, normal operation, operation with partial load and run-down. Depending on the objective of the analysis, it can also be relevant to consider testing, maintenance and emergency situations. The operating phase or the period of time for analysis should also be defined.

The performance measures predicted should be defined. In production availability and deliverability predictions, a reference level that provides the desired basis for decision-making should be selected. It should also be decided whether to include the production performance effect from turnarounds (see ISO 14224:2016, 3.94), as well as those major accident type of events normally identified and assessed with respect to safety in risk analyses.

The analysis methodology for use should be decided on the basis of study objectives and the predicted performance measures.

D.3 Procedure

D.3.1 Preparation

A review of available technical documentation should be performed as the initial activity, as well as establishing liaison with relevant disciplines. Site visits can be performed and are recommended in some cases.

All input documentation should be reviewed, liaison with relevant disciplines should be established, and sites should be visited, if necessary.

D.3.2 Study basis

The documentation of study basis has two main parts: system description and reliability data.

The system description should describe, or refer to documentation of, all technical and operational aspects that are considered to influence the results of the production performance analysis and that are required to identify the system subject to the analysis, e.g. design basis, piping and instrumentation diagrams, process flow diagrams, operation and maintenance strategies, reliability data, maintainability data, equipment data (e.g. capacities), cause and effect matrices, production profiles.

Reliability data should be documented. A reference to the data source should be included. Reference can be made to engineering or expert judgement, but an historically based data estimation should be used if one can be determined.

The basis for quantification of reliability input data should be readily available statistics and system/component reliability data, results from studies of similar systems or expert/engineering judgement. Performance and operability review (POR) sessions can be used to predict plant-specific down times. In the analysis, the approach taken for reliability data selection and qualification should be specified and agreed upon by the involved parties.

D.3.3 Model development

The model development includes the following activities:

— functional breakdown of the system;

— evaluation of the consequences of failure, maintenance, etc., for the various subparts;

— evaluation of events for inclusion in the model, including common-cause failures;

— evaluation of the effect of compensating measures, if relevant;

— model development and documentation.

D.3.4 Analysis and assessment

D.3.4.1 Performance measures

Various performance measures may be used to evaluate the performance of the object subject to analysis; see Clause G.1. Production availability and deliverability (whenever relevant) are the most frequently used measures. Depending on the objectives of the production performance analysis, the project phase and the framework conditions for the project, the following additional performance measures may be used:

— proportion of time or number of times production (delivery) is equal to or above demand (demand availability);

— proportion of time or number of times production (delivery) is above zero (on-stream availability);

— proportion of time or number of times the production (delivery) is below demand;

— proportion of time or number of times the production (delivery) is below a specified level for a certain period of time;

— proportion of time production (delivery) is below planned production (production unavailability) for specified increments of time;

— number of days with a certain production loss;

— resource consumption for repairs;

— availability of systems/subsystems;

— technical availability or operational availability.

As a predictor for the performance measure, the expected (mean) value should be used. The uncertainty related to this prediction should be discussed and, if possible, quantified (see D.3.7).

Annex G provides a guide on the elements for inclusion in the performance measure for predictions and for historical performance reporting.

D.3.4.2 Sensitivity analyses

Sensitivity analyses should be considered to take account of uncertainty in important input parameters, such as alternative assumptions, variations in failure and repair data or alternative system configurations.

D.3.4.3 Importance measures

In addition to the performance measure, a list of critical elements (e.g. equipment, systems, operational conditions and compensatory means) should be established. This list assists in identifying systems/equipment that should be considered for production assurance and reliability improvement.

There is a large number of component importance measures in literature on reliability theory, which can be used to establish such lists. Many of these are developed to measure importance in safety systems but can work in any traditional system availability analysis, typically performed by RBD or FTA. When production is considered, most of the common importance measures in reliability theory are not suited, but for several of these, it is possible to make only small adjustments in order to adapt them to production performance analysis. For instance, the Birnbaum measure, as described in Reference[76] can be interpreted as the difference in system state when the component is functioning and when it is not functioning. By considering the difference in production when the component is functioning or not, a slight variant of the Birnbaum measure can be used in production performance analyses.

Software tools for production performance analysis usually include some kind of importance measure algorithm. Such algorithms can be linked to importance measures in reliability theory, but have a more practical approach. A common concept is the evaluation of the component's contribution to production loss or unavailability. Some pitfalls related to this measure and its interpretation is addressed in Reference[78] which also gives an interpretation of the covariance between system and component suited for production systems. There are also other importance measures developed more specifically for multi-state production systems, e.g. in Reference[75].

D.3.5 Reporting and recommendations

The various steps in the production performance analysis, as described in D.3.1 to D.3.4, and all assumptions should be reported.

The appropriate performance measures should be reported for all alternatives and sensitivities.

Recommendations identified in the analysis should be reported. A production assurance management system should be used to follow up and decide upon recommendations. Recommendations can concern design issues or further production performance analyses/assessments. In the latter case, the interaction with the PAP is evident. Furthermore, recommendations can be categorized as relating to technical, procedural, organizational or personnel issues. Recommendations can also be categorized by whether they affect the frequency or the consequence of failures/events.

D.3.6 Major accidents and rare long duration events

Production assurance activities like production availability analysis or system availability analysis will normally analyse and quantify the risk of identified failure and consequences like production unavailability or system unavailability, whereof some can be due to infrequent and/or serious events with long production and/or system down time. These could be classified as:

— Type A: Major accidents (see 3.1.32) caused by various type of hazardous events (see Annex H);

— Type B: Infrequent critical equipment failures with long production and/or system down time. Such events are not considered to be major accident even though long production or operational down time can result.

These events should be distinguished from the more frequent events, which are considered in analyses of production availability and deliverability. The expected value contribution from such event is normally a rather small quantity, which is an unrepresentative contribution to the production loss. If the event occurs, the actual loss would be large and this could mean a dramatic reduction in the production availability or deliverability.

Concerning type A, the consequences for production as a result of major accidents in production and transportation systems are normally considered in the quantitative risk analysis (QRA). The results from such analysis can be included in the production performance analysis report in order to show all production loss contributors, and for overall risk management purposes. The use of production loss category G2 in Table G.1 or production loss category E2 in Table G.4 can be relevant to reveal such events in the overall analysis results.

Concerning type B, the probability of occurrence of these events and the production consequences can be part of the analysis model, depending on analysis approach (see e.g. I.5.2). The handling of such events should be addressed in the analysis and possible uncertainty in results arising from such events should be mentioned (see D.3.7).

Additional guidance is given in Annex H.

D.3.7 Handling of uncertainty

The uncertainty related to the value of the predicted performance measure should be discussed and, if possible, quantified. The quantification can have the form of an uncertainty distribution for the performance measure or a measure of the spread of this distribution (e.g. standard deviation, prediction interval).

The main factors causing variability (and hence uncertainty in the predictions) in the performance measure should be identified and discussed. Also, factors contributing to the uncertainty as a result of the way the system performance is modelled should be covered.

Importance and sensitivity analyses can be carried out to describe the sensitivity of the input data used and the assumptions made (see e.g. Reference[83]).

Where stochastic random sampling techniques are applied in production availability analyses, corresponding mean values along with mean (p50), upper and lower bound (p10 and p90) values should be reported. See also I.5.2.

Annex E
(informative)

Reliability and production performance data

E.1 Collection of reliability data

E.1.1 General

Systematic collection and treatment of operational experience is considered an investment and a means for improvement of production and safety critical equipment and operations. The purpose of establishing and maintaining databases is to provide feedback to assist with the following:

— product design;

— current product improvement;

— establishing and calibrating the maintenance and the spare-parts programmes;

— condition-based maintenance;

— identifying contributing factors to production unavailability;

— improving confidence in predictions used for decision support.

E.1.2 Equipment boundary and hierarchy definition

A clear boundary description is imperative, and a strict hierarchy system should be applied.

Boundaries and equipment hierarchy should be defined according to ISO 14224:2016, Annex A. Major data categories are defined as follows:

— installation data: description of installation from which reliability data are collected;

— inventory data: technical description of equipment, plus operating and environmental conditions;

— failure data: failure-event information, such as failure mode, failure impact, failure cause, etc.;

— maintenance data: corrective-maintenance information associated with failure events, and planned or executed preventive maintenance event information.

E.1.3 Data analysis

To predict the time to failure (or repair) of an item, a probability model should be determined. The type of model depends on the purpose of the analysis. An exponential lifetime distribution can be appropriate. The model, if it is expected to delineate a trend, should allow the use of a time-dependent failure rate.

The establishment of a failure (or repair) time model should be based on the collected reliability data, using standard statistical methods.

E.2 Qualification and application of reliability data

The establishment of correct and relevant reliability data (i.e. failure and associated repair/down time data) requires a data-qualification process that involves conscious attention to the original source of data, interpretation of any available statistics and estimation method for analysis usage. Suitable reliability data management and coordination are needed to ensure reliability data collection for selected equipment and consistent use of reliability data in the various analyses.

Selection of data should be based on the following principles.

- Data should originate from the same type of equipment and, if possible, originate from identical equipment models.
- Data should originate from equipment using similar technology.
- Data should originate from periods of stable operation, although early-life or start-up problems should be given due consideration. This also includes data from testing and inspection during the operation (see Figure 6 in ISO 14224:2016).
- Data should, if possible, originate from equipment that has been exposed to comparable operating and maintenance conditions.
- Data from laboratory testing, e.g. accelerated lifetime testing and reliability testing during technology development and technology qualification. In addition, data from performance testing prior to operation (e.g. FAT and SIT). Such pre-operational data should normally be entitled 'pre-operational/ test reliability data', as opposed to actual field operating experience.
- The basis for the data used should be sufficiently extensive.
- The number of inventories and failure events used to estimate or predict reliability parameters should be sufficiently large to avoid bias resulting from "outliers".
- The repair time and down time data should reflect site specific conditions.
- The equipment boundary for the originating data source and analysis element should match as far as possible (study assumptions should otherwise be given).
- Population data (e.g. accumulated operating time, observation period) should be indicated to reflect the statistical significance (uncertainty related to estimates and predictions) and the "technology window".
- Data sources should be quoted.

Data from event databases (compliant with ISO 14224:2016) provide a relevant basis for meeting these recommendations. In case of scarce data, it is necessary to use engineering judgement and to do a sensitivity analysis of input data.

E.3 Production performance data

Production performance data at facility/installation level should be reported in such a way that systematic production assurance can be carried out. The type of installation and operation determines the format and structure of performance reporting. Annex G outlines the types of events that are important to cover for a production facility. It is necessary to establish the relationship between facility-performance data and critical-equipment reliability data. Assessment of actual performance should be carried out by the installation operator on a periodic basis in order to identify specific trends and issues requiring follow-up. The main contributors to performance loss and areas for improvement can be identified. In this context, reliability techniques can be used for decision-support and calibration of performance predictions. Comparisons with earlier performance predictions should be done, thereby gaining experience and provide feedback for future and/or other similar performance predictions.

When reporting production loss, the failure reporting in computerized maintenance management information system (CMMIS) for the associated equipment, which cause production loss, should apply ISO 14224:2016 to enable linkage between production critical equipment failure and production loss.

Annex F
(informative)

Performance objectives and requirements

F.1 General

The specification of production assurance objectives and requirements can be considered for system design, engineering and purchase of equipment, as well as for operations in defined life cycle periods. In this respect, IEC 60300-3-4:2007 should also be considered.

In addition, provisions of this annex can be applied when specifying production assurance objectives in documentation for scope of work, invitation to tender (ITT), etc.

F.2 Specifying production assurance

The purpose of specifying production assurance is to ensure correct handling of safety and production assurance aspects and to minimize economic risk. The cost of design, production and verification of the system with a specified level of reliability or production assurance should be considered prior to stating such production assurance requirements.

Quantitative or qualitative objectives/requirements may be specified. Requirements should be realistic and should be compatible with the technological state of the art. It should be stated whether the specification is an objective or a requirement.

High attention should be given to establish well defined and unambiguous reliability objectives and requirements, enabling suppliers to design reliability into their supplied systems as early as possible in the project phase.

a) The goals and requirements within a production assurance specification should include, but not be limited to the following:

   — limitations and boundaries;

   — application of the system;

   — faults, failure modes, and planned/unplanned down time;

   — definition of the period of time for which the production assurance requirements apply (e.g. from first oil and to the end of design life);

   — operating conditions and strategies;

   — environmental conditions;

   — maintenance conditions and strategies;

   — methods intended for application to verify compliance with the production assurance requirements;

   — when numerical production assurance requirements are specified, the corresponding confidence levels should be specified;

   — definition of non-conformance to the requirement;

   — how non-conformance should be handled.

b) Quantitative requirements may be expressed on the basis of performance measures, such as the following:

— production availability (or production unavailability);

— system availability (or system unavailability);

— technical availability (or technical unavailability);

— operational availability (or operational unavailability);

— reliability (survival probability at time *t* of an item);

— time to failure;

— active repair time;

— preparation and/or delay (e.g. mobilization time for spare parts);

— repair workshop cycle time.

c) Qualitative requirements may be expressed in terms of any of the following:

— design criteria for the product;

— system configuration;

— inherent safety (acceptable consequence of a failure);

— production assurance activities to be performed.

Suppliers meet a variety of reliability requirements ranging from component level, all the way to the overall field level as presented in Figure F.1. The reliability requirements can be a mix of operator/project specific requirements combined with references to applicable standards and practices. This situation can result in ambiguity and lack of consistency and standardisation, and can potentially reduce the value of the production assurance activities, and should therefore be properly managed by applying the principles in this document.

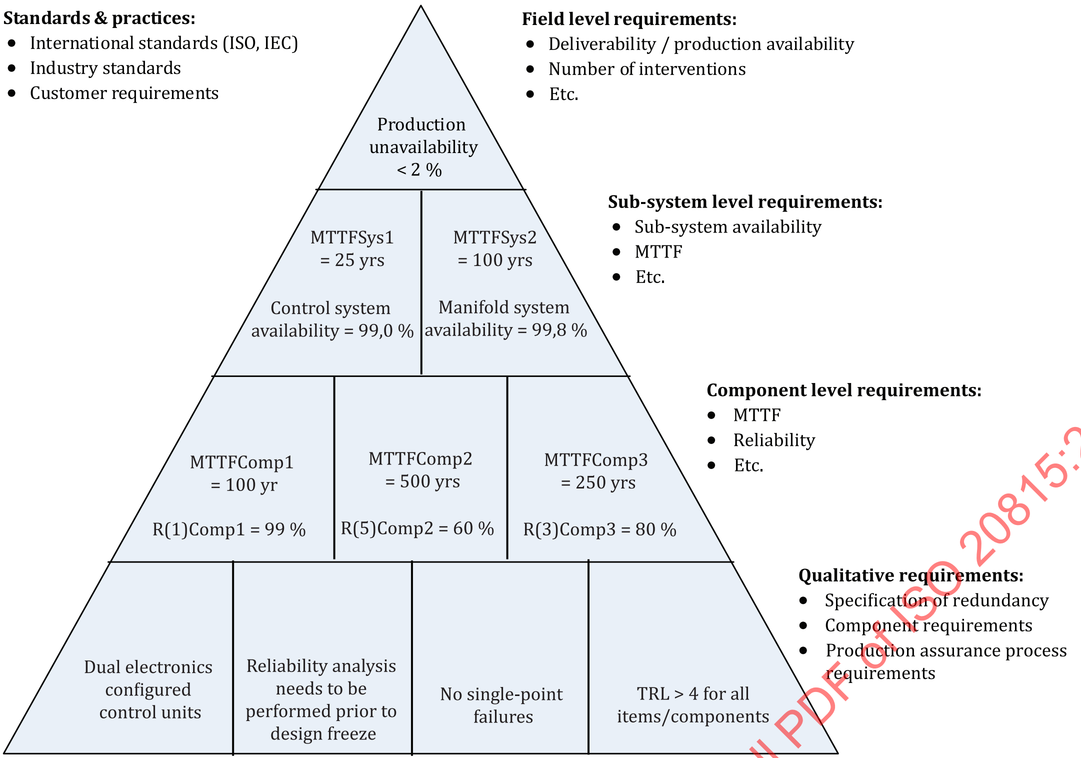


Figure F.1 — Typical reliability requirements — Subsea application example

F.3 Verification of requirement fulfilment

Implicitly, as a result of specifying reliability requirements, the suppliers and operators are expected to provide documentary evidence that the equipment performance is monitored (ref. Process 9 in Clause B.7) to assess if required reliability is in practice.

The method of verification of requirement fulfilment should be stated. Verification can be by:

— field or laboratory testing;

— analysis;

— field performance evaluation after delivery;

— documented relevant field experience.

The reliability requirements should as far as practicable be expressed in measurable terms, such that analytical methods can be used to make judgements on reliability achievement.

Data for calculations should be based on recognized sources of data, such as the results obtained from operational experience on similar equipment in the field or from laboratory tests. The classification of reliability data sources in ISO 14224:2016, Table D.5 should be applied. The reliability data should be agreed between the supplier and the customer.

Considerations should be given to confidence levels and uncertainty in the results, reference is made to D.3.7 for uncertainty considerations.

Annex E in ISO 14224:2016 provides a list of KPIs that can be relevant for use when defining and in follow-up of performance objectives and requirements.

F.4 Safety and environmental considerations

Safety systems have a vital function in petroleum, petrochemical and natural gas industries where such systems range from simple mechanical safety devices to safety instrumented systems. Safety systems contribute to meet HSE objectives and requirements, but can also affect production and operations.

Reliability objectives and requirements for safety systems and functions may be defined as part of the activities described in this annex. HSE related international standards such as ISO 13702:2015, ISO 15544:2000 and ISO 17776:2016 can be relevant. Reference is made to IEC 61508-1:2010 and IEC 61511-1:2016 for a description of a framework for specification and management of functional safety requirements (SIL requirements) for safety systems. Guidance is also provided in Reference[72].

Reference is also made to Annex F in ISO 14224:2016 for aspects related to reliability data for safety systems, and to ISO/TR 12489:2013 that provides guidance to reliability modelling and calculation of safety systems. Both documents are essential with respect to realization of safety requirements.

Annex G
(informative)

Performance measures for production availability

G.1 General

Performance measures for production availability are used in analyses for prediction or planning, as well as for the reporting of historical performance in the operational phase. The performance measures include the effect of down time caused by a number of different events. It is imperative to specify in detail the different type of events and whether they should be included or excluded when calculating the performance measure. This annex provides a guide to this subject in order to achieve a common format for performance predictions and reporting among field operators.

Various detailed production-reporting systems exist, but the one selected should enable comparable/exchangeable field reporting as indicated below.

For a typical hydrocarbon production facility, the following measures can be of interest for predictions as well as for historical reporting:

a) Production (un)availability of oil for storage or for export, measured at the exit of the process facility.

b) (Un)availability (time-based) or production (un)availability (volume-based) of water injection. One can, in addition, estimate the production (un)availability of the production system, taking into account the production unavailability of water injection.

c) (Un)availability (time-based) or production (un)availability (volume-based) of gas injection. One can, in addition, estimate the production (un)availability of the production system, taking into account the production unavailability of gas injection.

d) (Un)availability (time-based) or production (un)availability (volume-based) of utility systems. One can, in addition, estimate the production (un)availability of the production system, taking into account the production unavailability of the utility systems.

e) Production (un)availability of gas for export, measured at the exit of the process facility.

f) Production (un)availability of gas for export according to contractual requirements (e.g. variable contractual nomination) and evaluation of penalties due to failure to fulfil contractual requirements.

g) Deliverability of gas export, measured at the delivery point and including the effect of compensating measures.

h) Production (un)availability of the subsea installation in isolation without considering downstream elements.

i) Loading availability; measured offshore or onshore.

j) On-stream (production) availability; fraction of time the flow out of the system exceeds zero.

k) Demand availability; fraction of time the flow out of the system satisfies demand.

l) (Un)availability of the process facilities in isolation.

m) (Un)availability of gathering or exporting hydrocarbon/petrochemical network (volume-based).

n) Mean volume of flared gas according to various flaring policies.

o) Top ten contributors to losses with relative values.

Depending on the objective of the study, the above result parameters may be annually established based on the production profile or for only a specific production period, e.g. the production-plateau period, first year, maximum-water-production period, etc.

The uncertainty related to the value of the predicted performance measures should be discussed and, if possible, quantified. For details, see D.3.7.

An illustration of the relationship between some production assurance terms is shown in Figure G.1.

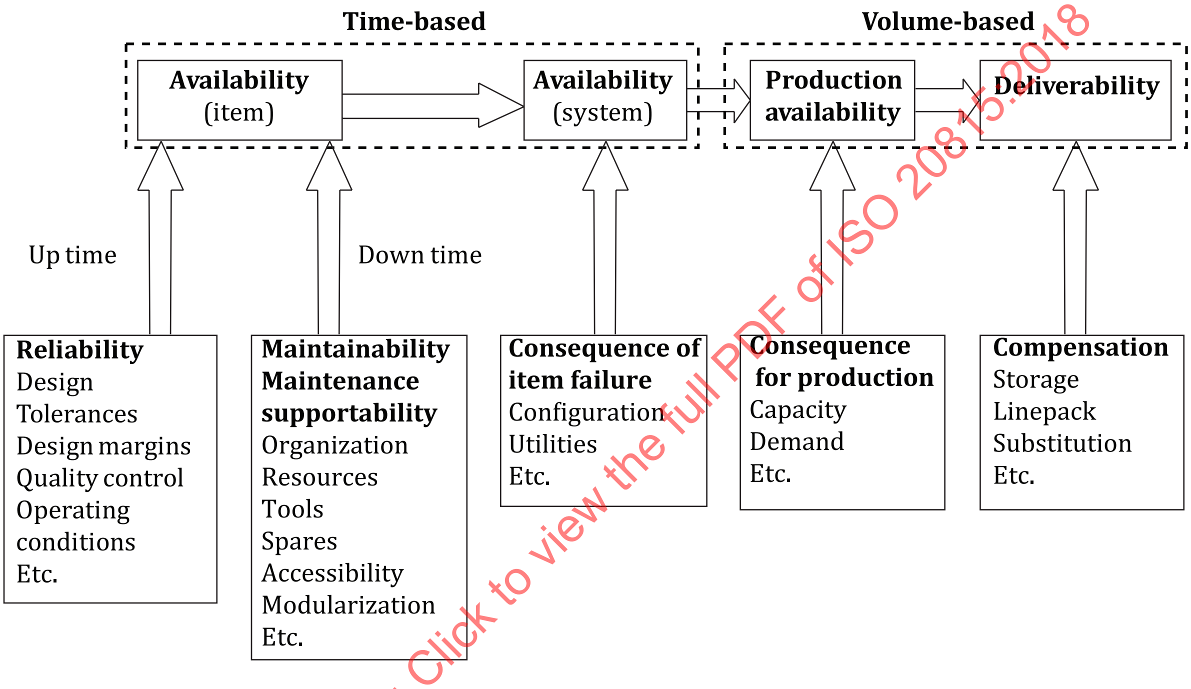


Figure G.1 — Illustration of the relationship between some time-based and volume-based production assurance terms

G.2 Production availability

G.2.1 Volume-based performance measures

Production availability (and deliverability), $P_A(T_1,T_2)$ over a time interval $[T_1, T_2]$ is a performance measure based on volume as defined in Formula (G.1).

$$P_A(T_1,T_2) = \frac{V_P(T_1,T_2)}{V_R(T_1,T_2)} \quad \text{(G.1)}$$

where

$V_P(T_1,T_2)$ is the produced volume over $[T_1, T_2]$;

$V_R(T_1,T_2)$ is a reference production volume over $[T_1, T_2]$.

Various types of performance reference measures may be chosen to enable the prediction of reporting of production availability. Ideally, the same reference level as used in production availability analyses phases should also be used when reporting historical production availability during the operational phase, the latter is typically production efficiency (see 3.1.46, Note 4 to entry). Some alternative reference measures are given in G.2.2 to G.2.6.

If the reference measures vary throughout the time (see cases G.2.2, G.2.5 and G.2.6), then:

— The estimated produced volume cannot be greater than the reference profile on average over the time interval basis (daily, monthly, yearly, etc.). In practice, this means that the calculation assumes that it is not possible to recover the production lost over the plateau period by using the overcapacity of the system under study when the reference production volume declines. However, regaining some production loss may be allowed given design capacity is not exceeded by producing above planned production levels for a limited time period, and the use of production availability estimation techniques can then reflect this.

— For a profile given on a yearly basis over 20 years, for example, the average of the estimated yearly production availability values (approach A-yearly average) is not equal to the overall production availability value estimated over the entire calculation period (approach B-lifetime average). Indeed, the “arithmetic” average of the estimated yearly values considers that each yearly value has the same weight within the final average whatever the reference production volume; whereas the “volumetric” production availability over the entire calculation period gives more weight to the years with a high reference production volume (i.e. the plateau period). Because both approaches are correct, it is very important to clearly define from the start which final production availability value has to be assessed, and to document the selected approach in the results.

— A third approach C can be to predict production availability for only one typical year in the lifetime, e.g. in plateau period, to be representative for the analysis.

When presenting results of production availability analyses, it is recommended that the mean value be presented together with the probabilistic distribution values to indicate the potential up- and downside range.

G.2.2 Contracted volume

If there is a sales contract, the contracted volume is the preferred reference level. The contracted volume may be specified with seasonal variations (swing). In that case, the swing profile should be used as the reference level. The contracted volume may also be specified as an average over a period of time, where the buyer nominates the daily supplies at some time in advance. When reporting historical production availability or deliverability, the reference-level volume should be the actual nominated volumes (it should be stated whether these nominations are, e.g. daily, weekly, monthly or yearly based). In a prediction, a distribution of volumes reflecting the foreseen variations in the nominated volumes should be used, but the ability of the facilities to deliver the maximum quantity should also be assessed.

G.2.3 Design capacity

The design capacity of the facility may be used as a reference level. This can be an appropriate reference level when only a part of the production chain, e.g. a process facility, is subject to analysis. The design capacity is easily available at an early phase in a project. A limitation is that production can be restricted by factors outside the system boundaries (e.g. well potentials), which can lead to misleading conclusions. Therefore, it is important to understand how oil or gas export depends on time-variable capacity limitations in the process design functions, such as oil treatment, gas processing, water treatment, gas injection, water injection, etc.

G.2.4 Well-production potential

The well-production potential may be a reference level, if it is less than the design capacity. This is especially the case during the production-decline period, but can also be the case in the production ramp-up period. It should be kept in mind that reservoir simulations are associated with uncertainty and should be handled accordingly in the analysis. The well-production potential can be adjusted during the operating phase.

G.2.5 Planned production volume assuming no down time (planned or unplanned)

Assuming that there is no down time in the maximum production volume (under the constraints of design capacities and well-production potentials), then this is the preferred reference level in production availability predictions, as well as in historical reporting. The uncertainty of reservoir simulations should be kept in mind. The length of the plateau period and the production rates in the decline period are uncertain.

Regarding integrating reservoir risk and production performance, it should be ensured that production profiles are risked only once when they are used as the reference level for a production availability estimation.

G.2.6 Planned production volume

The planned production volume, when expected down time is considered, may be used as a reference level when reporting historical production availability in the operational phase. However, the disadvantage of using this reference level measure, is that the costs of down time are concealed.

The planned production volume can also be set as the forecasted production volume for a defined time period of the planned initial operational life cycle phase (e.g. first year of planned production) as defined during project sanction decision making. The actual production volume for this planned time period can then be measured towards this forecasted volume using Formula (G.1). This production performance measure can then utilize project schedule loss categories (ref. loss category H in Table G.1) and other loss categories (e.g. loss category A1 - reservoir uncertainties) for providing information of deviations from original forecasted production volume.

G.2.7 Time-based performance measures

In addition to the volume-based performance measures, time-based measures can be used to calculate A_O, the average operational availability expressed as a ratio, as given in Formula (G.2):

$$A_O = \frac{T_u}{T_u + T_d} \tag{G.2}$$

where

T_u is the mean up time (MUT), estimated by using the actual up time observed in the field;

T_d is the mean down time (MDT), estimated by using the actual down times observed in the field. This down time includes planned and unplanned down time.

This operational availability corresponds to KPI number 7 in ISO 14224:2016, Table E.3. The technical availability is given as KPI number 8 in ISO 14224:2016, Table E.3.

The taxonomic level (see ISO 14224:2016, Figure 3) where this measure is used is preferably on system level or equipment item level, but can be used at plant or installation level.

The advantage of using operational availability as a time-based performance measure is that up time and down time is easy to establish compared to the reference level of the volume-based measures. On the other hand, the disadvantage is that this measure is not well suited to handle partial shutdowns. In some cases, the measure can be modified by defining up time and time in operation as well-years.

G.3 Production and time loss categories

The production availability parameter described in Clause G.2 is a single figure representing the average performance of a defined system. However, it is only one of several parameters that can be used. In downstream industries in particular, a wide range of performance measures is utilized.

These other parameters can include or exclude specific sources of loss of production or provide information about how the losses are expected to occur. In some cases, this can be of equal or greater importance than the overall production availability figure, for example the interruption frequency can be a key element of a gas-supply system.

Whatever measures are used for an analysis, it is necessary to state explicitly the basis on which they are calculated.

Tables G.1, G.4, G.5 and G.6 provide guidance on the events that should be included in production availability predictions and the reporting of historical production availability for a production system (i.e. volume-based performance measures). The production loss is a volume associated with an activity or an event that results in reduced utilization of production potential within a period of time. Production loss is registered according to the loss categories. The production loss volume being reported depends on the facility and can be oil, gas, condensate, etc. Time-based availability predictions or statistics can apply to the same event categorization (see Tables G.2 and G.3). Event categorization for other specific operations (e.g. pipe laying) and its associated system/equipment typically have another format, which is necessary to specify as required. Battery limits for the facilities, as well as any third-party processing, tie-ins, subsea installations, etc., should be clearly defined.

Tables G.1 to G.6 refer to one of the following business categories: upstream (Tables G.1 to G.3), midstream (Table G.4), downstream (Table G.5) and petrochemical (Table G.6). Examples of installations or plants/units for each of these business categories are given in ISO 14224:2016, Tables A.1 and A.2. It is important to distinguish between the production (or time) loss categorization shown in Tables G.1 to G.6 and the equipment failure and maintenance data requirements shown in ISO 14224:2016. This relationship is also addressed in Annex E.

Table G.1 — Production facility[a] — Production loss categories

Type of activity or event			Comments
A	**Wells (downhole and subsea/ surface)**		"Wells" covering downhole well completion equipment from (and including) the tubing hanger downwards to (and including) the reservoir, for surface and subsea completed wells. See also downhole well completion equipment in ISO 14224:2016, Table A.107. The subsea or surface wellhead and X-mas tree equipment are covered in loss categories B and C, respectively. See also ISO 14224:2016, Table A.90 and Table A.115, respectively.
	A1	Reservoir uncertainties	Production losses due to reservoir uncertainties (e.g. reservoir production less than anticipated). NOTE Can also be positive if reservoir produces more than anticipated; hence, it can be necessary to alter the reference level for the performance measurement.
	A2	Planned reservoir interventions	Production losses arising from planned activities to the reservoir, e.g. logging, fracturing, re-perforating, etc. The production availability impact depends on test design and procedures. The production down time and loss caused by the activity should be included. A possible positive effect on the production rate should also be considered, since this can influence the reference level for the performance measure. The reference level may be raised afterwards, but the investment to achieve this appears as a loss.
	A3	Unplanned reservoir interventions	Production losses arising from unplanned intervention in the reservoir. As in production loss category A2, the production down time and loss caused by the activity should be included, and it can require altering the performance reference level.
	A4	Well production testing	Production losses occurring whilst well production testing to check well production potential. Such type of reservoir testing has various production-loss impacts, depending on the configuration, available test equipment (flowmeter, test separator, test lines) and operational test procedure used.

[a] The production facility can be an installation or a plant/unit (or field infrastructure) for upstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A to G in this table cover losses within the value chain: wells – process – export. The production loss category H covers pre-production phase that can used when the delayed production due project schedule delays is addressed.

Table G.1 *(continued)*

Type of activity or event			Comments
	A5	Downhole well equipment failure	Production losses occurring until the initiation of well intervention. It covers preparation and/or delay. ISO/TR 12489:2013, Table 5 and ISO 14224:2016, Table 4 provide useful information to define precisely what to be covered in the loss category A5 versus A6.
	A6	Unplanned downhole well intervention	Production losses arising from the active repair of downhole well equipment failures (also called workover), including losses related to heavy lifts. Reliability-based contingency preparedness is anticipated by proper maintenance supportability and maintainability that can influence the scheduling and duration of well intervention.
	A7	Planned downhole well interventions or activities	Preventive maintenance for downhole well equipment. Production losses arising from periodic equipment testing (e.g. DHSV) and well inspection/ surveys. Also includes planned re-completions, zonal isolations, side-tracks, SIMOPS activities, etc.
	A8	Flow assurance (unplanned)	Production losses related to flow-assurance problems (e.g. hydrates, scaling, wax, asphaltenes), exclusively from and not accounted on the production loss categories A1 to A7.
	A9	Post-modification impact	Reduction or shutdown in production caused by a modification project (after run-in), e.g. side-tracking, re-completion, etc.
B	**Subsea installations**		Covers subsea X-mas tree, subsea flowlines or subsea pipelines, subsea production control (e.g. dynamic and static umbilicals), subsea manifolds, subsea valves and risers. Subsea processing and associated subsea electrical power distribution is also covered. Hence, all equipment subsea from tubing hanger to riser/umbilical topside/onshore termination. See also ISO 14224:2016, A.2.6 for subsea equipment classes that can be covered. Production loss in the subsea export facilities (e.g. export riser and SSIV) can be covered in loss category E4.
	B1	Subsea equipment failure	Production losses occurring until subsea intervention starts. This category normally also covers category B4 as an event is usually logged against equipment.
	B2	Unplanned subsea intervention	Production losses arising from active repair of failed subsea equipment and may include downhole/other intervention required to undertake subsea repair. Reliability-based contingency preparedness is anticipated by proper maintenance supportability and maintainability that can influence the scheduling and duration of subsea intervention.
	B3	Planned subsea interventions or activities	Preventive maintenance for subsea equipment. Production losses arising from planned activities that include preventive maintenance (e.g. X-mas tree), planned flow-assurance activities, testing, inspection, etc., on subsea equipment.
	B4	Flow assurance (unplanned)	The production down time and loss related to flow-assurance problems (e.g. hydrates, scaling, wax, asphaltenes, etc.).
	B5	Post-modification impact	Reduction or shutdown in production caused a modification project (after run-in), for example new subsea template/subsea manifold tie-ins.
C	**Production facilities**		Topside and onshore developments covering production facilities (e.g. dry X-mas trees, topsides manifolds and piping, valves and onshore pipelines, etc.). See also ISO 14224:2016, Table A.3 for upstream related systems that can be covered.
	C1	Production facilities equipment failure	Production losses occurring until corrective maintenance starts.
	C2	Unplanned production facilities maintenance	Production losses arising from repair of failure, which may include other maintenance required to undertake repair. Reliability based contingency preparedness is anticipated, by proper maintenance supportability and maintainability that can influence the scheduling and duration.
	C3	Planned production facility maintenance	Production losses arising from planned activities that include preventive maintenance (pigging), testing, inspection, etc., on equipment.

[a] The production facility can be an installation or a plant/unit (or field infrastructure) for upstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A to G in this table cover losses within the value chain: wells – process – export. The production loss category H covers pre-production phase that can used when the delayed production due project schedule delays is addressed.

Table G.1 *(continued)*

Type of activity or event			Comments
	C4	Flow assurance (unplanned)	The production down time and loss related to flow-assurance problems.
	C5	Post-modification impact	Reduction in or shutdown of production caused by a modification project (after run-in), e.g. pipeline tie-ins.
D	**Process and utilities**		Covers process and utility functions located topsides or onshore. See also ISO 14224:2016, Table A.3 for upstream related systems that can be covered.
	D1	Equipment failure and repair	Production losses related to failure and corrective maintenance; the corrective maintenance itself can be split, if needed. This covers failure of utility systems (e.g. methanol), auxiliary systems (e.g. main power), etc.
	D2	Preventive maintenance	Reduction in production caused by the execution of preventive maintenance (e.g. due to safety-barrier procedures); includes equipment testing of topsides safety equipment that affects production.
	D3	Process/ operational problems	Process upsets due to separation problems, low set points for sensors, testing/ diagnosing process facilities. It also includes human errors that cause production losses and may also include losses due to burn-in (early life failure) of modification projects and flow assurance issues.
	D4	Post-modification impact	Reduction in or shutdown of production caused by a modification project (after run-in), e.g. well compression, tie-ins from other facilities, etc.
E	**Export facilities**		Covers main export activities of tanker offtake or pipelines.
	E1	Storage limits	Shutdowns caused by full storage on offshore platform, FPSO or dedicated FSU.
	E2	Loading operations	Unplanned shutdowns caused by cargo handling/inert gas/ballast and/or other offloading equipment failures. Planned shutdowns.
	E3	Shuttle tanker delay	Shutdowns caused by external issues, such as a shuttle tanker being unable to accept cargo due to weather or technical reasons.
	E4	Export pipeline	Shutdowns in pipeline transportation system. Subsea pipeline coverage is given in ISO 14224:2016, A.2.6.7.
	E5	Downstream restrictions	Planned, and/or unplanned shutdowns caused by downstream receiving/process facilities outside the boundary limits (third-party issues). It may also cover third-party processing within a field infrastructure. Turnarounds for downstream facilities are also covered in this loss category. Downstream restrictions can be in a midstream, downstream or petrochemical installation.
	E6	Flow assurance	Flow assurance problems for processed products in pipeline, both planned (e.g. pigging) or unplanned (e.g. hydrate plug removal).
F	**Turnaround and modification**		—
	F1	Turnaround	Full shutdown due to integrity management or regulatory requirements. It is important to capture losses due to the planned period of the turnaround and also losses from any unplanned extension to the turnaround.
	F2	Modification	Full shutdown due to modification (e.g. tie-in or major module installation/ modification). Losses arising after run-in (post-modification) are recorded in category A9, B5, C5 or D4. It is important to capture losses due to the planned period of the modification and also losses from any unplanned extension to the modification.
G	**Other**		—
	G1	Bad weather	Production impact due to weather.

[a] The production facility can be an installation or a plant/unit (or field infrastructure) for upstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A to G in this table cover losses within the value chain: wells – process – export. The production loss category H covers pre-production phase that can used when the delayed production due project schedule delays is addressed.

Table G.1 *(continued)*

Type of activity or event			Comments
	G2	Safety and environmental	Safety or environmental related events or shutdown required due to safety contingency (e.g. ship collision risk) or accidental spill of oil, chemicals or synthetic materials, where there has been or can be a significant effect of pollution on the environment.
	G3	Labour conflicts	—
	G4	Environmental permits/limits	Reduced production to accommodate environmental discharge permits/ discharge limits (flaring, produced water disposal, oil in water limits, chemical discharge limits, etc.)
	G5	Security	Terrorism, riots, etc.
	G6	Authority restrictions	Restrictions by country regulatory bodies, national quotas, OPEC, etc.
	G7	Product quality deviations	Out of product specification (below and above specification).
	G8	Commercial	Losses caused by production constraints due to commercial aspects of the business
H		**Pre-production**	—
	H1	Project schedule delays	Losses due to slippage of actual first-oil date from planned first-oil date due to project delays. Wells and facility schedule losses should be reported in categories H2 and H3.
	H2	Wells schedule delays	Production losses due to slippage of drilling programme, resulting in the actual reservoir potential being less than the planned reservoir potential due to wells starting late. This can be compensated if the wells have a higher-than-expected flow rate. Only applicable in ramp-up and plateau phases and can require altering the performance reference level.
	H3	Facilities schedule delays	Production losses associated with equipment not being operational on the planned start dates or taking longer to commission and ramp up to maximum capacity. Only applicable in ramp-up phase.

[a] The production facility can be an installation or a plant/unit (or field infrastructure) for upstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A to G in this table cover losses within the value chain: wells – process – export. The production loss category H covers pre-production phase that can used when the delayed production due project schedule delays is addressed.

Table G.2 — Upstream drilling rig[a] — Time loss categories

Type of activity or event			Comments
A		**Rig drilling**	Reporting of drilling-rig time loss; covers platform rigs, mobile drilling units, etc., and covers, e.g. drilling, regular BOP and safety-equipment-related activities, logging/coring, orienting the well, running and cementing casings/liners activities and others; exploration and production drilling.
	A1	Moving from one well to the next	Activities carried out to move the rig from one location to another, such as removing and re-installing anchor lines of floating rigs in offshore scenarios. NOTE This is normally not a time loss category for one rig operation, but can be used to reflect drilling rig fleet utilization.
	A2	Rig down time due to rig equipment failure	Activities developed to repair equipment that is essential to proceed with normal operations, including possible safeguards on the well for repairing and others, e.g. setting a temporary plug in the well, pulling/running/repairing/re-installing the BOP, other repair-related activities, including to accessories such as logging tools. NOTE The time loss arising due to rig equipment failure can be further categorized using the drilling equipment classes and/or other relevant equipment categories in ISO 14224:2016, Table A.4.
	A3	Rig down time due to well problems	Combating a possible kick, fishing activities, re-setting or correcting the well-head installation, reaming, re-drilling, working on a mechanically unstable well, adjusting drilling-fluid parameters, correcting cement job, and others.
	A4	Waiting on operations	Waiting for something to proceed with intervention operations, e.g. waiting on weather, spare parts, materials or others.

[a] The drilling rig can be an installation or a plant for the upstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The time loss categories A1 to A4) in this table cover losses for a separate drilling rig or a drilling rig located as part of another upstream facility. Any production loss arising from the drilling rig operations is covered in Table G.1. The time loss categories can also be used for a drilling rig fleet. Further guidance for reporting of time loss during drilling operations can exist, and will typically reflect in further detail the operational phase (activities) when a time loss occurs.

Table G.3 — Upstream installation and intervention vessel[a] — Time loss categories

Type of activity or event			Comments
A	**Intervention and workover**		Covers all major intervention equipment, including platform rigs, mobile drilling units, coiled tubing systems, ROVs; includes checking or setting safety barriers in the well before intervention, regular BOP and safety-equipment-related activities, running/installing X-mas tree, gravel packer and tubing activities, and others. Installation (e.g. completion, pipe-laying, subsea equipment) and intervention (e.g. workover, manifold retrieval).
	A1	Moving from one location to the next one	Activities carried out to move the installation or intervention resources from one location to the next one. NOTE This is normally not a time loss category for one installation or intervention operation, but can be used to reflect vessel fleet utilisation.
	A2	Installation and intervention equipment failure	Activities developed to repair equipment that is essential to proceed with normal operations, including possible safeguards on the well for repairing and others, e.g. setting a temporary plug in the well pulling/running/repairing/re-installing the BOP; other repair-related activities, including to accessories such as logging tools. NOTE The time loss arising due to equipment failure can be further categorized using relevant equipment classes in ISO 14224:2016, Table A.4.
	A3	Waiting on operations	Waiting for something to proceed with intervention operations, e.g. waiting on weather, spare parts, materials or others.

[a] The installation and intervention operation for the upstream business category can involve a variety of installations and plants, e.g. MODU, SISV or installation vessel; see ISO 14224:2016, Tables A.1 and A.2. Any production loss arising from these operations can be addressed separately using Table G.1. The time loss categories can also be used for e.g. an intervention vessel fleet. Further guidance for reporting of time loss during operations can exist, and will typically reflect in further detail the operational phase (activities) when a time loss occurs.

Table G.4 — Midstream facility[a] — Production loss categories

Type of activity or event			Comments
A	**Pipeline**		Covers only line pipe, flanges, block valves, etc.
	A1	Planned interventions	Losses associated with planned activities that include preventive maintenance, testing, inspection, inspection pigging, surveys, etc.
	A2	Unplanned activities and equipment failures	Production impact arising from repair of pipeline failure, including third-party damage; also includes logistic delays. Plus geotechnical problems: pipeline movement, river crossing wash outs, etc.
	A3	Flow assurance	Flow assurance (hydrates, etc.), flow-assurance pigging plus failure of drag-reducing agents.
	A4	Post-modifications impact	Losses associated with modification work, i.e. tie-ins.
	A5	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the boundary limit of the terminal (third-party issues).
B	**Pump/Compressor station**		All equipment and activities within boundary limit of the pump/compressor station, including process and utilities (power, chemicals, instrument air, etc.).
	B1	Planned interventions	Losses associated with planned activities that include preventive maintenance, safety testing, inspection, etc.
	B2	Unplanned activities and equipment failures	Losses associated with unplanned activities, e.g. failure of prime movers and utilities (instrumentation, power, etc.).

[a] The midstream facility can be an installation or a plant (or infrastructure) for the midstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A to E in this table cover losses within this part of the value chain, and battery limits will need to be properly defined to differentiate between production losses covered by Table G.1 and Table G.5.

Table G.4 *(continued)*

Type of activity or event			Comments
	B3	Process/ operational problems	Process upsets, including logistic delays (e.g. on unmanned facilities); real trips including human errors.
	B4	Post-modifications impact	Losses associated with modification work, i.e. adding new pumps/compressors to increase capacity.
C		**Terminal**	Oil/condensate terminal (all production losses described in categories B1 to B4 preceding and the production losses listed in categories C1 to C3).
	C1	Offloading	These are shutdowns caused by (e.g. full-storage) offloading equipment failures or the tanker not being present, loading stopped due to bad weather, etc.
	C2	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the boundary limit of the terminal (third-party issues).
	C3	Product quality deviation	Product out of specification (below or above specification).
D		**LNG plants, gas plants, etc.**	Including all production losses described in categories B1 to B4 preceding and the production losses listed in categories D1 and D2).
	D1	Product quality deviation	Product out of specification (below or above specification).
	D2	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the boundary limit of plant (third party issues).
E		**Other**	—
	E1	Turnarounds	Can be considered as excluded both in predictions and for historical reporting (e.g. when turnarounds are defined in sales contracts).
	E2	Accidental events	Safety-related events. Down time caused by major accident type of nature should be reported separately in predictions.
	E3	Environmental permits/limits	Reduced production to accommodate environmental discharge permits/ discharge limits (flaring, water disposal, oil in water limits, chemical discharge limits, etc.).

[a] The midstream facility can be an installation or a plant (or infrastructure) for the midstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A to E in this table cover losses within this part of the value chain, and battery limits will need to be properly defined to differentiate between production losses covered by Table G.1 and Table G.5.

Table G.5 — Downstream facility[a] — Production loss categories

Type of activity or event			Comments
A		**Downstream facility**	Process plants typically consist of a number of process units
	A1	Equipment failure and repair	Production losses related to failure and corrective maintenance. This covers failure of process and utility systems, such as power, instrumentation.
	A2	Preventive maintenance	Losses associated with planned activities that include preventive maintenance (periodic test of safety equipment, testing and inspection, etc). See also Figure 6 in ISO 14224:2016.
	A3	Process/ operational problems	Process upsets, including logistic delays, real trips and human errors.
	A4	Product quality deviation	Losses arising from product out of specification requiring that it needs to be re-processed, disposed or given away.

[a] The downstream facility can be an installation or a plant (or infrastructure) for the downstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A1 to A9 in this table cover losses within this part of the value chain. The battery limits will need to be properly defined, also with respect to interfaces to production losses covered by Table G.4.

Table G.5 *(continued)*

Type of activity or event			Comments
	A5	Domino losses	Losses caused by shutdown/slowdown of other process units.
	A6	Turnaround and modification	Losses associated with planned turnarounds (major overhauls of process units planned well in advance). It is important to capture losses due to the planned period of the turnaround and also losses from any unplanned extension to the turnaround.
	A7	Commercial	Losses caused by production constraints due to commercial aspects of the business.
	A8	Accidental events	Safety-related events. Down time caused by major accident type of nature should be reported separately in predictions.
	A9	Environmental permits/limits	Reduced production to accommodate environmental discharge permits/ discharge limits (flaring, water disposal, oil in water limits, chemical discharge limits, etc.)
[a] The downstream facility can be an installation or a plant (or infrastructure) for the downstream business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A1 to A9 in this table cover losses within this part of the value chain. The battery limits will need to be properly defined, also with respect to interfaces to production losses covered by Table G.4.			

Table G.6 — Petrochemical facility[a] — Production loss categories

Type of activity or event			Comments
A	**Petrochemical facility**		Petrochemical process plants typically consist of a number of process units.
	A1	Equipment failure and repair	Production losses related to failure and corrective maintenance. This covers failure of process and utility systems, such as power, instrumentation.
	A2	Preventive maintenance	Losses associated with planned activities that include preventive maintenance, (periodic test of safety equipment, testing and inspection, etc.). See also Figure 6 in ISO 14224:2016.
	A3	Process/ operational problems	Process upsets, including logistic delays, real trips and human errors.
	A4	Product quality deviation	Losses arising from product out of specification requiring that it needs to be re-processed, disposed or given away.
	A5	Domino losses	Losses caused by shutdown/slowdown of other process units.
	A6	Turnaround and modification	Losses associated with planned turnarounds (major overhauls of process units planned well in advance). It is important to capture losses due to the planned period of the turnaround and also losses from any unplanned extension to the turnaround.
	A7	Commercial	Losses caused by production constraints due to commercial aspects of the business.
	A8	Accidental events	Safety-related events. Down time caused by major accident type of nature should be reported separately in predictions.
	A9	Environmental permits/limits	Reduced production to accommodate environmental discharge permits/ discharge limits (flaring, water disposal, oil in water limits, chemical discharge limits, etc.)

[a] The petrochemical facility can be an installation or a plant (or infrastructure) for the petrochemical business category, as shown in ISO 14224:2016, Tables A.1 and A.2. The production loss categories A1 to A9 in this table cover losses within this part of the value chain, and battery limits will be needed to related interfaces to production losses covered by Table G.4.

Annex H
(informative)

Relationship to major accidents

H.1 General

Risk analysis (e.g. QRA) and emergency preparedness analysis (see Clause I.20) will include serious and infrequent hazardous events that can cause long-term shutdown of production or operation, and that can imply major loss or even zero production or plant/system operation over a long time. These events fall within the category of major accidents (see 3.1.32) and should be distinguished from other infrequent events that are considered in the analyses of production availability and deliverability. The major accidents should be treated separately in production performance analyses (see D.3.6).

The main purpose of this annex is to advise that there is a need in production performance analysis to highlight this in the analysis work, and rather refer to the risk analysis (e.g. QRA) and emergency preparedness analysis where such events are analysed. This means that the total production unavailability or total system unavailability can be lower than what is predicted in the production performance analysis. The project risk management for asset or facility would need to manage this total risk picture, as some of the events causing major accidents can also benefit from using this document (e.g. risk-reduction by equipment reliability management).

Typical major offshore accidents can be caused by hazards and accident conditions, such as the following (ref. also NORSOK Z-013:2010):

1) process accidents (unignited and ignited leaks, fires and explosions);
2) risers/landfall and pipeline accidents;
3) storage accidents (liquid and gas);
4) loading/offloading accidents;
5) blowouts and well releases;
6) accidents in utility systems (leaks of chemicals, fires, explosion of transformers etc.);
7) accidents caused by external impact and environmental loads, e.g. collision, falling/swinging loads, helicopter crash, earthquake, waves;
8) structural failure (including gross errors);
9) loss of stability and/or buoyancy (including failure of marine systems).

In addition, security issues can be considered in the context of risk analysis. The term threat should only be used for such security considerations, and not be mixed with other equipment failure characteristics, as threat is related to an intended action. See ISO 22300:2012.

Important factors in the analysis of major accidents are considered in more detail in the remainder of this annex.

The purpose of the availability analyses is to predict the actual production availability, A, for the installation for the time period considered. This quantity is uncertain (unknown) when the analysis is carried out and it is necessary to predict it. The uncertainty related to the value of A can be expressed by a probability distribution $H(a)$, with mean or expected value, $\bar{A}$ being the predictor of A. A Monte-Carlo study of the production availability is generally performed by generating a sequence of independent, identically distributed quantities, for example $A_1, A_2, ..., A_n$, from the probability distribution, $H(a)$. The distribution can be estimated from the sample $A_1, A_2, ..., A_n$.

In theory and as far as the uncertainty distribution $H(a)$ is concerned, there is no problem in including major accidents in this analysis. If a major accident results in a production loss, z, and its associated probability equals p, this can be reflected in the distribution, H. However, using the "full distribution" makes it difficult to predict A using the expected value. In this case, the spread around the mean would be very large and the probability density can have a bimodal form very different from the typical Gaussian distribution. The case is that the expected value of the contribution from the major accident is normally a rather small quantity, namely $p \cdot z$, which is an unrepresentative contribution to the production loss. If the major accident type of event occurs, the actual loss would be z and this can mean a dramatic reduction in the production availability, A.

If the time period considered is long, then the probability that a major accident will occur can be quite large, and consequently the contribution $p \cdot z$ significant. Hence, in such cases, the inclusion of major accidents is more meaningful.

H.2 Criterion for attention in analyses

The consequences for production as a result of major accident in production and transportation systems may be identified in a production availability analysis, but it is recommended to refer to the risk analysis (e.g. QRA). In general, major accidents should be included in overall risk and financial analyses, but not in production availability analysis. The PAP can be used to give criteria for how defined major accidents are handled by e.g. defining a probability of occurrence for the lifetime applicable for the analysis and the production loss in case of an occurrence of these major accidents.

It should be considered to refer to the predicted production availability loss value estimated, if this is a part of the QRA. This enables a consistency check of the framework conditions and reference level, making it comparable to predictions in the production availability analysis.

In analyses limited to subsystems, one should consider case-by-case whether the major accidents should be included.

Annex I
(informative)

Outline of techniques

I.1 General

Production performance analyses, such as reliability and availability analyses, are systematic evaluations and calculations that are carried out to assess the performance of a system. The system can in this context be at different taxonomic levels (see ISO 14224:2016, Annex A), for example, it can be an overall production or transportation system, a compression train, a process shutdown system, a drilling and well system or, it can be a pump or a valve. These analyses are part of a production assurance programme (PAP).

It is useful to apply the following as a guide:

— Production performance analysis considers the production from facilities with several production levels, e.g. offshore or onshore production systems, installation(s) or operation(s).

— Availability analysis considers the up times of two states (running/not running) of items (components, equipment, units and systems).

— Reliability analysis considers the first failure of two states of items (components, equipment, units and systems).

Reliability is important for safety and production performance. In the context of a PAP, it can be used to evaluate the probability that the first failure occurs after a given period of time.

Availability is mainly focused on the time during which an item is running correctly. In the context of a PAP, it can be appropriate for single components or for production trains made of component in series. It may also be used to perform "availability allocations" in order to establish the requirements for the providers of such components.

This annex briefly describes the following analysis methods and techniques:

— failure modes and effects analysis (I.2);

— fault tree analysis (I.3);

— reliability block diagram (I.4);

— Monte-Carlo simulation (I.5.2);

— behavioural modelling (I.5.3);

— flow network analysis (I.5.4);

— Petri net analysis (I.5.5);

— design reviews (I.6);

— hazard and operability study (I.7);

— performance and operability review (I.8);

— reliability testing (I.9);

— human factors (I.10);

- software reliability (I.11);
- dependent, common cause and common mode failures (I.12);
- life data analysis (I.13);
- reliability-centred maintenance analysis (I.14);
- risk-based inspection analysis (I.15);
- test interval optimization (I.16);
- spare parts optimization (I.17);
- methods of structural reliability analysis (I.18);
- life cycle cost analysis (I.19);
- risk and emergency preparedness analyses (I.20);
- technology maturity assessment (I.21);
- Markov process analysis (I.22);
- Bayesian belief network (I.23);
- life time extension analysis (I.24);
- analysis on weather influence on production performance (I.25);
- loading performance analysis (I.26).

Reference can be made to the documents cited in these clauses or to reliability analysis textbooks for more detailed descriptions.

I.2 Failure modes and effects analysis

A summary of failure modes and effects analysis (FMEA) and failure mode, effect and criticality analysis (FMECA) is given in Table I.1.

Table I.1 — Failure modes and effects analysis (FMEA) and failure mode, effect and criticality analysis (FMECA)

Analysis elements	Summary
Analysis description	Two bottom-up techniques for analysing and establishing systematically the effects of potential failure modes.
Objective of analysis	FMEA is a systematic technique for establishing the effects of potential failure modes within a system. The analysis can be performed at any level of assembly. This can be done with a criticality analysis, in which case it is called an FMECA. FMECA is a semi-quantitative analysis, where the failure probability and the consequence data are used to assess the criticality of each failure mode. It is a systematic methodology to increase the inherent reliability of a system or product. It is an iterative process of identifying failure modes, assessing their probabilities of occurrence and their effects on the system, isolating the causes, and determining corrective actions or preventive measures. When the analysis is done from a functional standpoint, it is usually performed at a plant or unit level, whereas if the focus is on the hardware, it usually descends down to the maintainable-item level. The amount of data required is different depending on the focus (see Tables I.2 to I.4 for details). While it is most often used in the early stages of the design process to improve the inherent reliability, the FMECA technique is equally useful in addressing system safety, availability, maintainability, or logistics support.
Reference to existing standards	MIL-STD-1629A:1998 IEC 60812:2006
Overall need for information	The analysis is an inductive and systematic process in which individual failures at component level are generalized into potential failure modes at system level. The structured method consists of the following steps: a) system definition (both from functional and hardware standpoints); b) identification of failure modes (it is necessary that it includes the operational and environmental conditions present when failure occurs); c) determination of failure causes (understanding of the related failure mechanism and identification of the lowest level in hierarchy affected); d) assessment of effects (in terms of system performance, reliability, maintainability and safety); e) identification of detection means (to verify that suitable detection means exist for all critical failure modes); f) classifications of severity (to assign priorities to corrective actions; typically with 3 or 4 levels); g) estimation of probability of occurrence (from failure rates based on experience or public data bases or classification into 3 or 4 levels by using engineering judgement); h) computation of the criticality index (a combination of the probability of occurrence and the severity of the failure); i) determination of corrective action (by eliminating the cause of the failure, decreasing their probability of occurrence, improving failure detection or reducing the severity of the failure).

I.3 Fault tree analysis

A summary of the fault tree analysis (FTA) is given in Table I.2.

Table I.2 — Fault tree analysis (FTA)

Analysis elements	Summary
Analysis description	This is a graphical top-down method used to analyse the logical links between failure of an overall system and the failures of its components and to perform probability calculations.
Objective of analysis	There are several objectives such as the following examples: — build a graphical representation of the combinations of the individual components failures that lead to failure of the whole system and, by doing so, obtain the Boolean equation linking the undesirable event (at the whole system level) to the failure of the individual components; — analyse qualitatively the reliability/availability (see Notes 1 to 4) of the system by identifying the combinations of basic failures leading to the undesirable event. These combinations of failures are the so-called “minimal cut sets” (coherent FT) or “prime implicants” (non-coherent FT); — analyse semi-quantitatively the reliability/availability (see Notes 1 to 4) of the system by sorting its minimal cut sets (or prime implicant) in order of decreasing probabilities; — calculate the probability of failure (see Notes 1 to 3) of the whole system; — evaluate various importance factors in order to assess the impact of the failures of the individual components; — evaluate the impact of the individual input uncertainties over the result(s).
Reference to existing standards	IEC 61025:2006
Overall need for information	A fault tree represents a Boolean process, which is used to calculate the probability of the corresponding overall event from the individual probabilities of the basic events appearing in the formula. Therefore, the inputs used are the pure probabilities of failures, for which it is necessary to evaluate from the reliability parameters of the related components: — probability of failure; — probability of human error; — failure frequency; — failure rates, repair rates; — test interval, test efficiency.
Notes	NOTE 1 FTA normally deals with two-states components and systems. NOTE 2 From probabilistic calculation point of view, an FT allows to combine the time-independent probabilities of its leaves to obtain the time-independent probability of failure of the modelled system. Nevertheless, when the leaves behave independently all along the time, an FT can be used to calculate the unavailability or the failure frequency of the modelled system.

Table I.2 *(continued)*

Analysis elements	Summary
	NOTE 3 Except when some hypotheses (e.g. no repair) are met, unreliability cannot be exactly assessed by using FTA. Nevertheless, when failures are quickly revealed and repaired, FT can be used to calculate the conditional failure intensity (Vesely failure rate, see ISO/TR 12489:2013, 3.1.21), which leads to good approximation of the system unreliability (see IEC 61078:2016). NOTE 4 FTA can be used to analytically calculate the unavailability of a production system, but is not suited to assess its production availability when several production levels are taken under consideration. NOTE 5 FTA is also a very good support for performing common cause failure analyses, sensitivity analyses and uncertainty analyses. NOTE 6 The fault tree can also be used in combination with cause-consequence diagram to analyse underlying causes of the event failure NOTE 7 FT and MPA can be mixed within FT driven Markov processes where small Markov processes are used to models the leaves of the FT and where the FT provides the logic linking the leaves (see ISO/TR 12489:2013). This allows to build Markov models for large systems and prevent the combinatorial explosion of the number of states. NOTE 8 The state of the art in Boolean calculation is to use the binary decision diagrams (see IEC 61078:2016). This allows to handle large models, with many repeated events (leaves) and encompassing millions of cut sets, in short computation time.

I.4 Reliability block diagram

A summary of a reliability block diagram (RBD) is given in Table I.3.

Table I.3 — Reliability block diagram

Analysis elements	Summary
Analysis description	Formally this is a logic diagram representing how a system works and allowing probabilistic calculations. An RBD is made of two-states boxes (representing individual components) linked together according to the functional logic of the overall system.
Objective of analysis	The purpose of RBD is to build a logical model remaining as close as possible to the system architecture and representing those components that need to be operating/failed in order that the overall system be operating/failed. An RBD is generally an output of the functional analysis of the system under study. From a logical point of view, an RBD represents a Boolean equation. It is equivalent to a fault tree and can be used for exactly the same purpose with the same computation techniques (see Table I.2). An RBD can be considered as a kind of "electrical" circuit. Looking for combinations of component failures leading to system failure is equivalent to looking where this circuit can be "cut." Hence, the origin of the term "cut set."
Reference to existing standards	IEC 61078:2016
Overall need for information	Same as for fault tree (see Table I.2).
Notes	NOTE 1 This is more a representation than an analysis method (contrarily to FTA which is both). Less abstracted than FTA, this is the method preferred by engineers to represent systems.

Table I.3 *(continued)*

Analysis elements	Summary
	NOTE 2 An RBD deals only with two-states components and systems. FTA and RBD have the same mathematical background and therefore the same possibilities and limitations (see Table I.2). NOTE 3 An RBD is not suited to production assurance analysis, which require flow networks that accommodate multi-state systems. NOTE 4 RBD and MPA can be mixed within RBD driven Markov processes where small Markov processes are used to models the boxes of the RBD and where the RBD provides the logic linking the boxes (see IEC 61078:2016). This allows to build Markov models for large systems and prevent the combinatorial explosion of the number of states.

I.5 Models for production availability calculations

I.5.1 General

Except for the Markov process analysis (MPA), classical models are not well adapted for production availability calculations. MPA is only efficient for very small systems. Therefore, it is necessary to use models able to:

— handle the complex behaviour of production systems;

— obtain the various probabilistic parameters needed;

— perform calculations quickly on industrial size system.

A solution widely adopted is to perform "Monte-Carlo simulations" on "behavioural models".

I.5.2 Monte-Carlo simulation principles

Monte-Carlo simulation is a computation technique that replaces the analytical calculations by statistical calculations. It is based on the simulation of a great number of production system histories according to the following principle:

— The instants of occurrence of the events (e.g. failures, repairs, bad weather, rig mobilization) occurring over a given history are calculated by using random numbers according to relevant probability distributions.

— The relevant parameters (e.g. production losses, number of spare parts used, work load, time to first failure) are captured over the given history in order to constitute statistical samples.

— When a sufficient number of histories has been accumulated, statistical calculations are used to estimate the wanted parameters (e.g. production availability, average production losses, average work load, mean time to first failure) from the statistical samples.

Monte-Carlo simulation is very well suited for production availability prediction of a production facility. It overcomes the limitations of analytical calculations and can be used to model a variety of situations including complex failure and repair distributions, the effects of different repair policies, redundancy, operational aspects, etc. In addition, it allows mixing easily stochastic and deterministic events.

The variability in the simulation result parameters requires attention to handling of uncertainty (see D.3.7). The number of Monte-Carlo simulations to be run in an analysis mainly depends on the probability of occurrence of the events of interest within the period which is simulated, and the number of events to simulate to reach the events of interest.

When applying this computation technique, sufficient number of simulations are required to ensure results converge within an acceptable tolerance range and to the level of precision required.

I.5.3 Behavioural modelling

Before performing Monte-Carlo simulation, it is necessary to build the model being simulated. It is necessary that such model has the following characteristics:

— approximate as closely as possible the actual system behaviour (e.g. react when events occur);

— encompass all elements having an impact on production (e.g. production flow through the various equipment, system response to component failure or repair, operation, maintenance, spare parts and flaring philosophies, SIMOPS, production profiles, etc.);

— code in a concise way the vast number of potential states of the production system.

The relevant mathematical framework to achieve above requirements consists of the so-called “finite-states automata,” which generalize all the classical models (RBD, FTA and MPA).

Such “finite-state automata” are widely used for applications including Markov graphs, flow networks, Petri nets, formal languages (proprietary or published), etc. Their performances and modelling capacities vary over a large range and it is recommended to verify carefully that the particular software package selected is suitable for a given production availability study.

I.5.4 Flow network analysis

A summary of the flow network analysis (FNA) is given in Table I.4.

Table I.4 — Flow network analysis

Analysis elements	Summary
Analysis description	A flow network (FN) is similar to an RBD and represents a production system. It is composed of boxes (representing the production capacities of individual process components) linked together according to the circulation of the production flow throughout the production system. The flow network analysis (FNA) is not a single type of analysis, but rather a general description of the methodology and capabilities of various software tools which apply Monte Carlo simulation to some kind of network that represents a production system. The diagram can look like an RBD, an FN or a hybrid of these.
Objective of analysis	The first purpose of FNA is to build a flow model representing the production capacity of the system as a function of the production capacities of its components. This model depends on the software package used. Once established, the model can be used in Monte-Carlo simulation support to perform the calculations and evaluate the relevant production parameters, such as production availability, deliverability, demand availability, unavailability contribution from the various elements, storage volume levels, usage of resources and spare parts, including shortage, usage of utilities, including shortage. Then, with regards to the performance objectives and requirements defined in the PAP, the results can be used for decision support by doing sensitivity analysis on any of the input parameters.

Table I.4 *(continued)*

Analysis elements	Summary
Reference to existing standards	None
Overall need for info	The flow diagram itself can be drawn from the process flow diagrams (PFD) and process instrumentation diagrams (PID) of the system under study and the inputs includes those presented in Table I.2 (see also Table I.6). Inputs identified in I.5.3 are also needed, but cannot be graphically represented.
Notes	NOTE 1 FN is a representation widely used by engineers. It covers various realities ranging from RBD like models to more sophisticated models. NOTE 2 Some software tools have the possibility to apply multi-level networks or include fault trees/RBDs in the simulation. NOTE 3 Most of the proprietary software packages devoted to production availability calculations are based on Monte Carlo simulation on RBD/FN-like models. Their modelling capacities and computation performances vary over a large range and it is wise to analyse them cautiously before using them. NOTE 4 Flow network (FN) and Petri nets (PN) can be mixed into "FN driven PN" models where small sub-PNs are used to model the behaviours of the boxes of a given FN and where the FN is used as guidelines to link the boxes together. NOTE 5 Optimization algorithms should be applied at product separation or mixing points to reflect real life conditions, e.g. such that production from high value streams are optimized.

I.5.5 Petri net analysis

A summary of the Petri net analysis (PNA) is given in Table I.5.

Table I.5 — Petri net analysis

Analysis elements	Summary
Analysis description	This is a graphical method that uses Petri nets (represented as finite-state automata) to build a dynamic behavioural model of the system. Potential events are represented by transitions and potential states by places. Arcs and predicates (equations) are used to model the conditions to validate transitions (i.e. events able to occur). Arcs and assertion (equations) are used to model when a transition is fired (i.e. an event occurs). Like FN, PN provide good support for Monte Carlo simulation.
Objective of analysis	The first purpose of PNA is to build a model describing accurately both function and dysfunction of production systems. According to the study this can include logistics, resources used by several users (e.g. a single repair team for several components) and the reconfiguration after a component failure or repair, etc. Once established, the model can be simulated step by step manually (i.e. by using a “stepper”) to verify that the behaviour reflects that of the actual production system. Then, the model provides an efficient behavioural model for Monte Carlo simulations which can be used to perform the calculations and evaluate the relevant production parameters such as production availability, deliverability, demand availability, unavailability contribution from the various elements, storage volume levels, usage of resources and spare parts, including shortage, usage of utilities, including shortage, production losses, flared gas quantity, maintenance man-hours, number of repairs performed by a given repair team, number of failures, load of the repair support. The shortest and/or the most probable sequences of event (scenarios) starting from the perfect state (if any) and leading to the fully failed state (if any) can also be obtained. Then, with regards to the performance objectives and requirements defined in the PAP, the results can be used for decision support requirements defined in the PAP, the results can be used for decision support by doing sensitivity analysis on any of the input parameters.