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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

ISO 20815 was prepared by Technical Committee ISO/TC 67, Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries, WG 4 Data collection.

Annex A, B, C, D and E are for information only.

Introduction

The petroleum and natural gas industries involve large 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.

This International Standard introduces the concept Production Assurance which covers activities implemented to achieve and maintain a performance which is at its optimum in terms of the overall economy and at the same time consistent with applicable framework conditions.

This International Standard recommends processes and activities for production assurance with the aim to establish the required input to select an economic optimal solution and its implementation in a life cycle perspective.

This International Standard focuses in particular on the processes needed for management of reliability and production availability.

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

1 Scope

This International Standard provides requirements and guidelines for systematic and effective planning, execution and use of reliability technology to achieve cost-effective solutions 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, quality and human factors;
- planning, execution and implementation of reliability technology;
- the application of reliability and maintenance data;
- reliability based design and operation improvement;
- establishment and use of reliability clauses in contracts.

This international standard covers analysis of reliability and maintenance of the components, systems and operations associated with exploration drilling, exploitation, processing and transport of petroleum, petrochemical and natural gas resources. This international standard focuses on production assurance of oil and gas production, processing and associated activities. For standards on equipment reliability and maintenance performance in general see IEC 60300-3-1 and the IEC60701 series.

It is also an objective of this international standard to arrive at a common understanding with respect to use of reliability technology in the various life cycle phases.

2 Normative reference

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

ISO 14224, *Petroleum 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.

3.1.1.
active maintenance time
that part of the maintenance time during which a maintenance action is performed on an item, either automatically or manually, excluding logistic delays

NOTE A maintenance action may be carried out while the item is performing a required function.

[IEC 60 050-191]

3.1.2.
availability
ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided

[IEC 60 050-191]

3.1.3.
common cause failure
failures of different items resulting from the same direct cause, occurring within a relatively short time, where these failures are not consequences of another

3.1.4.
corrective maintenance
maintenance which is carried out after a fault recognition and intended to put an item into a state in which it can perform a required function

[IEC 60 050-191]

NOTE For more specific information, see Figure 191-10 "Maintenance time diagram" in IEC 60 050-191.

3.1.5.
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

3.1.6.
design life
planned usage time for the total system

NOTE Design life should not be confused with MTTF. The system comprises several items. Items may be allowed to fail within the design life of the system as long as repair or replacement is feasible.

3.1.7.
down state
internal disabled state of an item characterised either by a fault, or by a possible inability to perform a required function during preventive maintenance

NOTE This state is related to availability performance.

[IEC 60 500-191]

3.1.8.
down (time)
time interval during which an item is in a down state

[IEC 60 500-191]

NOTE 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.

3.1.9.
downstream
business process most commonly in the petroleum industry to describe post production processes

NOTE Examples: Refining, transportation and marketing of petroleum products

3.1.10.
failure
termination of the ability of an item to perform a required function

NOTE 1 After failure the item has a fault.

NOTE 2 “Failure” is an event, as distinguished from “fault”, which is a state

3.1.11.
failure cause (root cause)
circumstances associated with design, manufacture, installation, use and maintenance, which have led to a failure

[EN 13 306]

3.1.12.
failure data
data characterising the occurrence of a failure event

3.1.13.
failure mode
effect by which a failure is observed on the failed item

3.1.14.
failure rate
number of failures relative to the corresponding operational time

NOTE 1 In some cases time can be replaced by units of use. In most cases 1/MTTF can be used as the predictor for the failure rate, i.e. the average number of failures per unit of time in the long run if the units are replaced by an identical unit at failure.

NOTE 2 Failure rate can be based on operational time or calendar time.

3.1.15.
fault
the state of an item characterised by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources

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

[IEC 60 500-191]

3.1.16.
item
any part, component, device, subsystem, functional unit, equipment or system that can be individually considered

[IEC 60 500-191]

3.1.17.
logistic delay
that accumulated time during which maintenance cannot be carried out due to necessity to acquire maintenance resources, excluding any administrative delay

[EN 13 306]

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

3.1.18.
lost revenue (LOSTREV)
total cost of lost or deferred production due to downtime

3.1.19.
maintainable item
item that constitutes a part, or an assembly of parts, that is normally the lowest level in the equipment hierarchy during maintenance

3.1.20.
maintenance
combination of all technical and administrative actions, including supervisory actions, intended to retain an item in, or restore it to, a state in which it can perform a required function

[IEC 60 500-191]

3.1.21.
maintenance data
data characterising the maintenance action planned or done

3.1.22.
maintainability (general)
ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.

[IEC 60 500-191]

3.1.23.
maintenance support performance
ability of a maintenance organisation, under given conditions, to provide upon demand, the resources required to maintain an item, under a given maintenance policy.

NOTE The given conditions are related to the item itself and to the conditions under which the item is used and maintained.

[IEC 60 500-191]

3.1.24.
mean time between failures (MTBF)
expectation of the time between failures

NOTE The MTTF of an item could be longer or shorter than the design life of the system.

[IEC 60 500-191]

3.1.25.
mean time to failure (MTTF)
expectation of the time to failure

NOTE The MTTF of an item could be longer or shorter than the design life of the system.

[IEC 60 500-191]

3.1.26.
midstream
business category involving the processing, storage and transportation sectors of the petroleum industry

NOTE Examples: Transportation pipelines, terminals, Gas processing and treatment, LNG, LPG and GTL.

3.1.27.
modification
combination of all technical and administrative actions intended to change an item

[IEC 60 500-191]

3.1.28.
observation period
time period during which production performance and reliability data is recorded

3.1.29.
operating state
state when an item is performing a required function

[IEC 60 500-191]

3.1.30.
operating time
time interval during which an item is in operating state

[IEC 60 500-191]

NOTE Operating time includes actual operation of the equipment or the equipment being available for performing its required function on demand.

3.1.31.
performance objectives
indicative level for the performance/reliability one wishes to achieve

NOTE Objectives are expressed in qualitative or quantitative terms. Objectives are not absolute requirements and may be deviated based on cost or technical constraints.

3.1.32.
performance requirements
required minimum level for the performance/reliability of a system or in a asset development project

NOTE Requirements are normally quantitative but may be qualitative.

3.1.33.
petrochemicals
business category producing petrochemical, i.e. chemicals derived from petroleum and used as feedstock for the manufacture of a variety of plastics and other related products.

NOTE Examples: Methanol, Polypropylene.

3.1.34.
preventive maintenance
maintenance carried out at predetermined intervals or according to prescribed criteria, and intended to reduce the probability of failure or the degradation of the functioning of an item

[IEC 60 500-191]

3.1.35.
production assurance analysis
systematic evaluations and calculations carried out to assess the production performance of a system

NOTE The term should be used primarily for analysis of total systems, but may also be used for analysis of production unavailability of a part of the total system.

3.1.36.
production assurance
activities implemented to achieve and maintain a performance which is at its optimum in terms of the overall economy and at the same time consistent with applicable framework conditions

3.1.37.
production availability
ratio of production to planned production, or any other reference level, over a specified period of time

NOTE 1 This measure is used in connection 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 2 The term injection availability may be used meaning the ratio of injection volume to planned injection volume.

3.1.38.
production performance
describes how a system is capable of meeting demand for deliveries or performance

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

NOTE 2 The use of production performance terms should specify whether it represents a predicted or historic production performance.

3.1.39.
redundancy
existence of more than one means for performing a required function of an item

3.1.40.
reliability
ability of an item to perform a required function under given conditions for a given time interval.

NOTE The term reliability is also used as a measure of reliability performance and may also be defined as a probability.

[IEC 60 500-191]

3.1.41.
reliability data
data for reliability, maintainability and maintenance support performance

3.1.42.
required function
function, or combination of functions, of an item which is considered necessary to provide a given service

[IEC 60 500-191]

3.1.43.
up state
state of an item characterised by the fact it can perform a required function, assuming that the external resources, if required, are provided

NOTE This relates to availability performance

[IEC 60 500-191]

3.1.44.
upstream
business category of the petroleum industry involving exploration and production

NOTE Examples: Offshore oil/gas production facility, drilling rig, intervention vessel

3.1.45.
uptime
time interval during which an item is in the up state

[IEC 60 500-191]

3.1.46.
variability
variations in performance measures for different time periods under defined framework conditions

NOTE The variations could be a result of the downtime pattern for equipment and systems, operating factors such as wind, waves and access to certain repair resources.

3.2 Abbreviated terms

For the purpose of this document, the following abbreviated terms apply.

CAPEX	capital expenditures
ESD	emergency shut down
FMEA	failure modes and effects analysis
FMECA	failure modes, effects and criticality analysis
FTA	fault tree analysis
GTL	gas to liquid
HAZID	Hazard identification
HAZOP	hazard and operability study
ILS	integrated logistic support
LCC	life cycle cost
LNG	liquefied natural gas
LOSTREV	lost revenue
LPG	liquefied petroleum gases
MTTF	mean time to failure
MTTR	mean time to repair
NPV	net present value
OPEX	operational expenditure
OREDA®	offshore reliability data
PAP	production assurance programme
POP	performance and operability review
RBD	reliability block diagram
RBI	risk based inspection
RCM	reliability centred maintenance
RISKEX	risk expenditure
SRA	structural reliability analysis
QA	quality assurance

4 Production assurance and decision support

4.1 Framework conditions

The objective associated with systematic production assurance is to contribute to the alignment of design and operational decisions with corporate and business objectives.

In order to fulfil this objective, technical and operational means as indicated in Figure 1 may be used during design or operation to change the performance level. Production assurance shall include surveillance of project activities and decisions which may have an undesired effect on the performance.

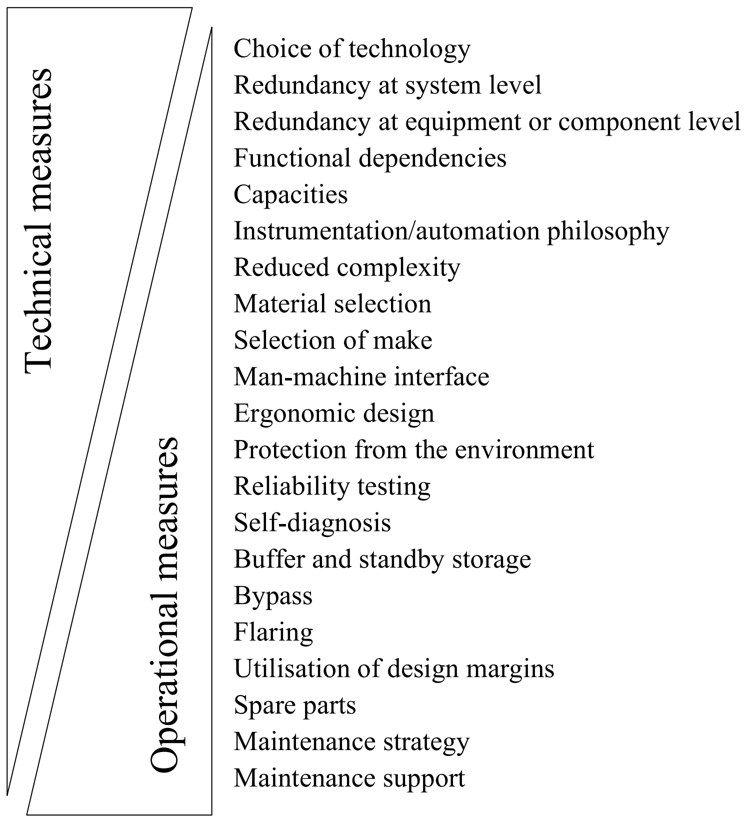

Figure 1 - important measures for control of production performance

4.2 Optimisation process

The main principle for optimisation of design or selection between alternative solutions is economic optimisation within given constraints and framework conditions. The achievement of high performance is of limited importance unless the associated costs are considered. This International Standard should therefore be considered together with ISO 15663, part 1 to 3.

Examples of constraints and framework conditions which will affect the optimisation process are:

- requirements to design or operation given in authority regulations;
- requirements given in standards;
- requirements to health, safety and environment;

- requirements to safety equipment resulting from the risk analysis and the overall safety acceptance criteria;
- project constraints such as budget, realisation time, national and international agreements;
- conditions in the sales contracts;
- requirements to market performance.

The optimisation process is illustrated in Figure 2. The first step is to identify alternative solutions. Then these shall be checked with respect to the constraints and framework conditions that apply. The appropriate production assurance parameters are predicted and the preferred solution is identified based on an economical evaluation/analysis such as a NPV analysis or another optimisation criterion. The process can be applied as an iteration process where the selected alternative is further refined and alternative solutions identified. Sensitivity analyses should be performed to take account of uncertainty in important input parameters. The execution of the optimisation process requires the production assurance and reliability function to be addressed by qualified team members.

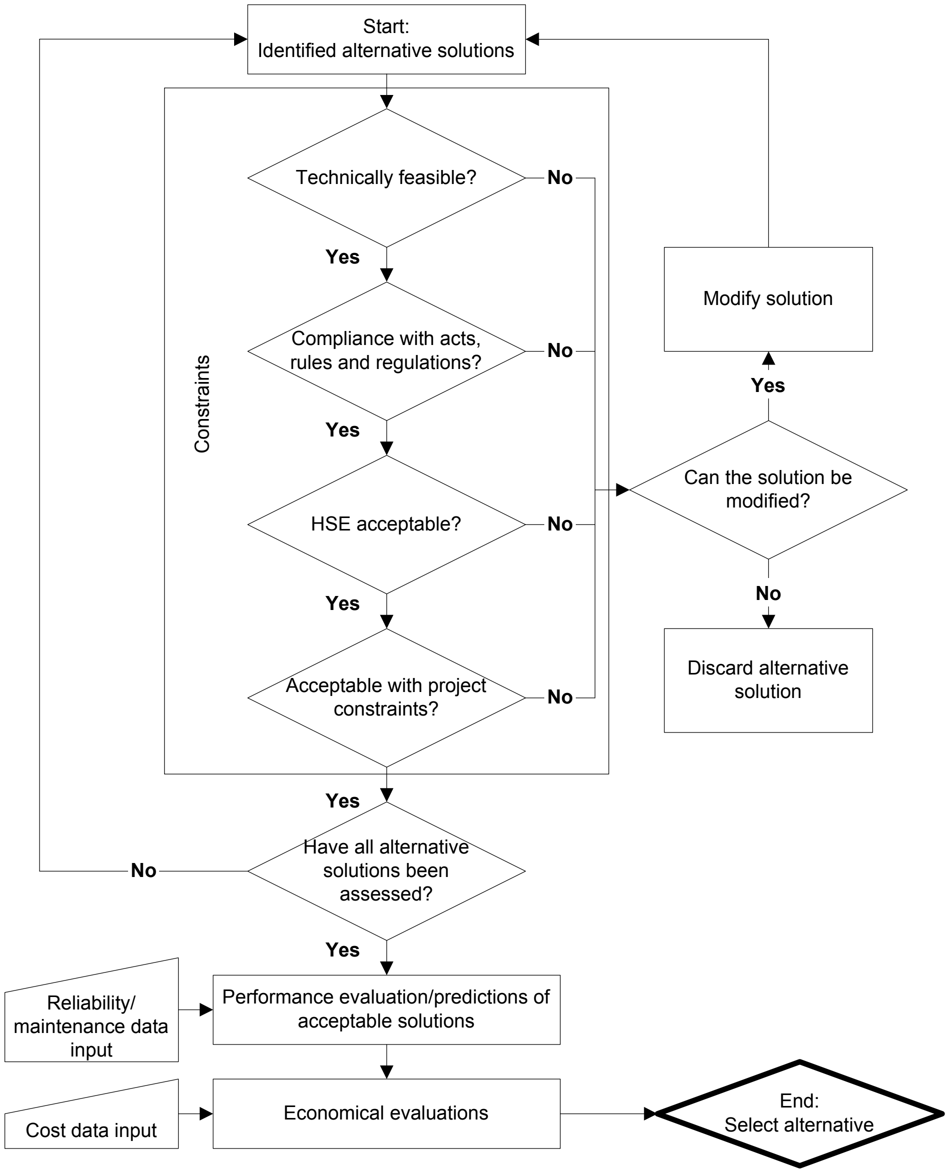

Figure 2— Optimisation process

4.3 Production assurance programme

4.3.1 Objectives

A production assurance programme (PAP) shall serve as a management tool in the process of achieving performance objectives by cost-effective means and shall be a living document through the various life cycle phases. A PAP shall be established for each asset development project and updated at major milestones as required as well as being established for existing fields in operation. The PAP shall:

- ensure systematic planning of production assurance/reliability work within the scope of the programme;
- define optimisation criteria;
- define performance objectives and requirements, if any;
- describe the production assurance activities necessary to fulfil the objectives, how they will be carried out, by whom and when. These shall be further outlined in separate production assurance or reliability activity plans;
- ensure that proper consideration is given to interfaces of production assurance and reliability with other activities.

The PAP shall be at a level of detail which facilitates easy updating and overall co-ordination.

4.3.2 Project risk categorisation

The level of effort to invest in a production assurance program to meet the business objectives needs to be defined for each life cycle phase. In practice the production assurance effort required will be closely related to the level of technical risk in a project. It is therefore recommended that one of the first tasks to be performed is a high level categorization of the technical risks in a project. This will enable project managers to make an initial general assessment of the level of investment in reliability resources that may have to be made in a project.

The project risk categorisation will typically vary from one company to another depending on a number of factors such as financial situation, risk attitude, etc. Hence, company specific risk categorisation schemes should be established. However, to provide some guidance on the process, a simple risk categorisation scheme is outlined below.

Projects are classified into three risk classes:

- high risk
- medium risk
- low risk

The features that describe the three risk classes are further outlined in Table 4.3-1. There will typically be a gradual transition between the three risk categories. Hence a certain degree of individual assessment will be required. However, the justification for the selected risk category for a project should be included in the production assurance plan issued in the feasibility or concept phase.

The project risk categorisation (high, medium and low) is further applied in Table 4.3-2 (see 4.3.3) to indicate what processes should be performed for the different project categories.

Table 4.3-1: Project risk categorisation

Technology	Operating envelope	Technical system scale and complexity	Organisational scale and complexity	Risk category	Description
Mature technology	Typical operating conditions	Small scale, low complexity, minimal change of system configuration	Small and consistent organisation, low complexity	Low	Low budget, low risk project using field proven equipment in same configuration and same team with similar operating condition as previous projects
Mature technology	Typical operating conditions	Moderate scale and complexity	Small to medium organisation, moderate complexity	Low-Medium	Low to moderate risk project using field proven equipment in similar operating envelope to previous projects but with some system and organisational complexity
Non mature technology for extended operating environment	Extended/aggressive operating environment	Large scale, high complexity	Large organisation, high complexity	Medium-High	Moderate to high risk project using either non mature equipment or with extended operating conditions. Project involves large, complex systems and management organisations
Novel technology				High	High risk project using new/novel technology in a new or different system architecture

4.3.3 Programme activities

Production assurance activities can be carried out in all phases of the life cycle of facilities to provide input to decisions regarding concept, design, manufacturing, construction, installation, operation and maintenance. Activities shall be initiated only if they are considered to contribute to added value in the project by improving quality of information to support decision making, or reduce economic or technological risk.

The production assurance activities to be carried out 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.

Compliance to this International Standard is limited to the tabulated processes and activities in clause 4 and clause 5.

If the processes and activities listed in clause 4 and clause 5 can be demonstrated to be non value adding for a specific delivery project, they can omitted.

Production assurance shall be a continuous activity throughout all life cycle phases. Important tasks of production assurance are to monitor the overall performance level, manage reliability of critical components and continuous identification of the need for production assurance activities. A further objective of production assurance is to contribute with technical or operational recommendations.

The processes and activities listed in clause 4 and clause 5 shall be focused on the main technical risks items initially identified through a top-down screening process. A criticality classification activity should assist in identifying performance critical systems that should be subject to more detailed analysis and follow-up.

This is to avoid reliability activities that are redundant, non value adding or too extensive.

The emphasis of the production assurance activities will change for the various life cycle phases. Early activities should focus on optimisation of the overall configuration while attention to critical detail will increase in later phases.

In the feasibility and concept phases, the field layout configuration with the preferred NPV distribution shall 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, RISKEX (cost or benefit of other risk) and revenue for each alternative.

These functions are in turn fed back into the operators NPV 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 this is recommended to be achieved through long term partnering of both suppliers and operators and suppliers and sub-suppliers. Such long term relationships will 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 e.g. implementing the resulting recommendations as specifications in the Invitations to Tender.

An overview of the production assurance processes are given in Table 4.3-2, while activity requirements for the processes are given in clause 5. The table provide recommendations (indicated by crosses – "x") on what processes should be performed as function of the project risk categorisation. The table also provides recommendations (indicated by crosses – "x") as to when the processes should be applied (in what life cycle phase).

Process 1 (reliability requirements) can be used to illustrate the interpretation of the table. This process, which is further described in clause 5, should be implemented for medium and high risk projects, and performed in the feasibility, concept design, engineering and procurement life cycle phases.

The life cycle phases indicated in Table 4.3-2 apply for a typical asset development project. If the phases in a specific project differ from those below, 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 will apply

Table 4.3-2— Overview of production assurance processes versus risk levels and life cycle phases

Production assurance processes for asset development				Life Cycle Phase						
				Pre contract award		Post contract award				
Low Risk Projects	Medium Risk Projects	High Risk Projects	Main Processes	Feasability	Conceptual Design	Engineering [a]	Procurement	Fabrication/Construction/Testing	Installation and Commissioning	Operation
	x	x	1. Reliability Requirements	x	x	x	x			
	x	x	2. Risk and Reliability in Design	x	x	x				
x	x	x	3. Reliability Assurance	x	x	x	x	x	x	x
x	x	x	4. Reliability Verification and Validation	x	x	x				
x	x	x	5. Project Risk Management	x	x	x	x	x	x	x
	x	x	6. Reliability and Qualification Testing		x	x	x	x		
x	x	x	7. Performance Tracking and Analysis						x	x
	x	x	8. Supply Chain Management				x			
x	x	x	9. Management of Change		x	x	x	x	x	x
	x	x	10. Reliability Improvement and Risk Reduction		x	x		x	x	x
x	x	x	11. Organisational learning	x	x	x	x	x	x	x

[a] Including pre-engineering, system engineering and detailed engineering

4.4 Alternative standards

Compliance to this International Standard for delivery projects can be achieved by following the listed processes and activities in clause. 4 and clause 5.

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

The table below show main production assurance and reliability processes described within this International Standard links to some of these standards. Work processes carried out in accordance with these standards will be considered to also satisfy the requirements for relevant processes in this International Standard.

However compliance to this International Standard is limited to the listed processes and activities in clause 4, 5 and 1, i.e. the alternative standards are not normative for this international standard.

The list of standards below is non exhaustive. Other standards may also cover specific requirements in this International Standard. If alternative standards are referred for compliance to specific requirements, it will be the responsibility of the user to demonstrate such compliance.

Please note that ISO 14224 compliance is listed as a normative reference, hence not included in the below table.

Table 4.4-1 - Alternative standards

Standard	1. Reliability Requirements	2. Risk and Reliability in Design	3. Reliability Assurance	4. Reliability Verification and Validation	5. Project Risk Management	6. Reliability and Qualification Testing	7. Performance Tracking and Analysis	8. Supply Chain Management	9. Management of Change	10. Reliability Improvement and Risk Reduction	11. Organisational learning
IEC 60300-1: “Dependability management Part 1: Dependability management systems”	X										
IEC 60300-2: Dependability management Part 2: Guidelines for dependability management			X	X							
IEC 60300-3-2: “Dependability management Part 3-2: Application guide Collection of dependability data from the field”							X				
IEC 60300-3-4: “Dependability Management - Part 3: Application Guide - Section 4: Guide to the Specification of Dependability Requirements”		X									
IEC 60300-3-9: “Dependability Management - Part 3: Application Guide - Section 9: Risk Analysis of Technological Systems”		X			X						
IEC 60300-3-10: “Dependability Management-Part 3-10: Application Guide–Maintainability”		X									
IEC 60300-3-14: “Dependability management - Part 3-14: Application guide - Maintenance and maintenance support”		X									
API 17N: “Reliability & technical risk management”	X	X	X	X	X	X	X	X	X	X	X
DNV-RP-A203: “Qualification procedures for new technology”						X					

5 Core production assurance processes and activities

5.1 General

The following clauses give requirements to the core production assurance and reliability processes and activities that should be carried out, as part of a production assurance program, in the various life cycle phases of a typical asset development project.

Other projects than asset developments, e.g. drilling units, transportation networks, major modifications, etc. will have phases that more or less coincides with those described in the following. The activities to be carried out may, however, differ from those described.

Hence, the production assurance program should be adapted for each part involved to ensure that it fulfils the business needs.

In addition to the production assurance processes and activities described in this chapter, a number of interacting processes are described in clause 1. These processes are normally outside the responsibility of the production assurance discipline, but information flow to and from these processes will be required to ensure that production performance and reliability requirements can be fulfilled.

Below illustrates what processes are defined as core production assurance processes and what are considered interacting processes. Details regarding objectives, input, output and activities for each of the processes are further described in clause 5.2 to 6.6 and in clause 1.

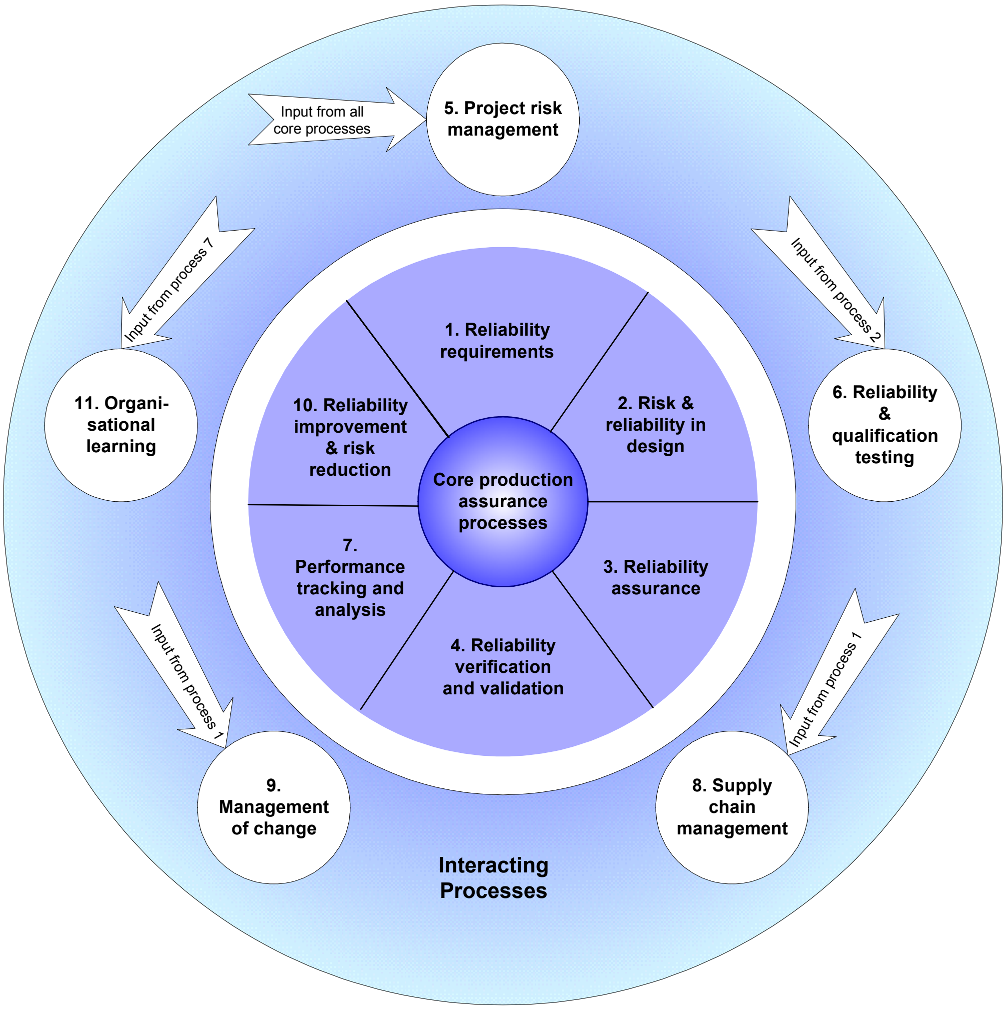

Figure 3: Core and interacting production assurance processes

5.2 Process 1: Reliability requirements

Unnecessary limitations in the form of unfounded performance requirements shall be avoided to prevent that alternatives which could have been favourable in respect of overall economy are rejected during the optimisation process.

Optimal production availability in the oil and gas business requires a standardized integrated reliability approach, as this chapter provides for asset development.

This is an economic optimisation problem, with defined framework conditions and constraints. This optimisation problem involves both production assurance and interfacing processes.

The constraints from other disciplines as outlined in Figure 2 shall be considered together with relevant performance measures (see Annex C) in the optimisation process.

In the feasibility and concept phases, the asset configuration with the preferred NPV distribution shall 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 (production unavailability), RISKEX (cost or benefit of other risk) and revenue for each alternative. These functions are in turn fed back into the operators NPV 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 the present overemphasis on CAPEX is avoided, and this is recommended to be achieved through long term partnering of both suppliers and operators and suppliers and sub-suppliers. Such long term relationships will 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 e.g. implementing the resulting recommendations as specifications in the Invitations to Tender.

Table 5.2-1: Description of production assurance process 1 - Reliability requirements

	Life cycle phase			
	Feasibility phase	**Concept phase**	**Engineering**	**Procurement**
Objective	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	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	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 which reliability standards to comply with.
Input	Alternative asset development plans. ***Activity: Production availability analysis (Process 2)*** Estimate the production availability for the field layouts specified as input on a system level ***Activities: Planning, reporting and follow up (Process 3)*** of the requirements	The selected asset development plan, with the estimated production availability formulated as a system requirement in the Invitation to Tender. Alternative field layout configurations. ***Process: 2 Risk and Reliability in Design*** ***Activity: C Production availability Analysis*** Estimate the production availability for the field configurations specified as input on a system level ***Process: 3 Reliability Assurance*** ***Activities:*** H Planning, I reporting and J follow up the requirements	Output from the concept phase.	Output from the engineering phase.

	Life cycle phase			
	Feasibility phase	Concept phase	Engineering	Procurement
Production Assurance Activities	Identify additional constraints. Initiate estimation of the production availability for the asset layouts specified as input on a system level	Initiate estimation of the production availability for the asset layouts. These estimates are aggregated from each main supplier's scope of supply, as defined by the asset development.	Define and allocate the production assurance requirements to the subsystems, as required. This definition is based on the production availability estimation in process 2.	Ensure that the reliability requirements are included in the tender documents, through interfacing with the procurement organisation.
Output	Input to estimation of the production availability Production availability estimates for the options specified as input. Estimated production availability for each option, to be formulated as a system requirement for the option to be selected.	Production availability estimates for the options specified as input, allocated according to each main supplier's scope of supply.	Subsystem production availability requirements for the selected option, as required. This includes the applied subsystem reliability input data (average downtime and failure frequencies).	Subsystem reliability requirements, including which reliability standards to comply with.

5.3 Process 2: Risk and reliability in design

Optimal technical safety and reliability must be 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, there is a need for early design for reliability to support the project development.

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

The feasibility and concept phase reliability activities shall focus on optimisation of overall configuration and identification of the critical subsystems, while attention in detail for the critical subsystems will increase in the engineering phase.

Table 5.3-1: Description of production assurance process 2 - Risk and reliability in design

	Life cycle phase		
	Feasibility phase	Concept phase	Engineering phase
Objective	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	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	Provide partial detailed design decision support.
Input	Alternative asset development plans ***Process: 3 Reliability Assurance, Activities:*** H Planning	The selected asset development plan, with the estimated production availability formulated as a system requirement in the Invitation to Tender. Alternative field layout configurations. ***Process: 3 Reliability Assurance, Activities:*** I reporting and J follow up the requirements	Selected field layout configuration Alternative design solutions, as they arise in the design process. ***Process: 3 Reliability Assurance, Activities:*** I reporting and J follow up the requirements

	Life cycle phase		
	Feasibility phase	Concept phase	Engineering phase
Production assurance Activities	**C Production Availability Analysis** The purpose of production availability analysis in this phase is to contribute to optimise the asset development plan. The production availability for alternative asset development plans should be established. The parameters below are guidance to establish such. - Fault tolerance, i.e. redundancy - Proven versus novel solutions - Flexibility, e.g. possibility for alternative routings, reconfigurations and future expansions - Maintainability, e.g. minimize the amount of downtime required for maintenance **B Equipment Reliability Analysis** The purpose of the equipment reliability analysis is to screen the delivery project to identify the critical parts, and then study such in more detail to identify possible improvements.	**C Production Availability Analysis** The purpose of production availability analysis in this phase is to contribute to optimise the field layout configuration. The production availability for 2-3 alternative layout configuration options shall be established. Identify such options, by varying the parameters below. - Fault tolerance, i.e. redundancy - Proven versus novel solutions - Simplicity, e.g. minimise the amount of required connections, which are potential sources of failures. - Overcapacity, e.g. in a degraded mode of operation, the system will still partially or fully fulfil the design intent - Flexibility, e.g. possibility for alternative routings, reconfigurations and future expansions - Maintainability, e.g. minimize the amount of downtime required for maintenance **B Equipment Reliability Analysis** The purpose of the equipment reliability analysis is to screen the delivery project to identify the critical parts, and then study such in more detail to identify possible improvements.	**C Production Availability Analysis** The purpose of production availability analysis in this phase is mainly to verify compliance to requirements, since most of the decisions influencing those are already made. However, recommendations for spare parts shall be established. **B Equipment Reliability Analysis** The purpose of the equipment reliability analysis is to screen the delivery project to identify the critical parts, and then study such in more detail to identify possible improvements. - Equipment quality, e.g. material selection
Output	Production availability estimates for the options specified as input. ***Process: 3 Reliability Assurance, Activities:*** I reporting and J follow up the requirements.	Production availability estimates for the options specified as input. ***Process: 3 Reliability Assurance, Activities:*** I reporting and J follow up the requirements.	Production availability estimates for the options specified as input. ***Process: 3 Reliability Assurance, Activities:*** I reporting and J follow up the requirements.

5.4 Process 3: Reliability assurance

This process is relevant for all life cycle phases and relates to management of the production assurance process and demonstration that the production performance and reliability requirements are adhered to. The main production assurance management tool shall be the production assurance plan (PAP). Further requirements to the PAP are described in 4.3.

Table 5.4-1: Description of production assurance process 3 - Reliability assurance

	Life cycle phase
	All phases
Objective	Planning; reporting and follow up of the production assurance activities to manage and demonstrate production assurance.
Input	The project plan is required in order to schedule the production assurance activities before the decisions are made, and after the required background is established. Reliability Process 5: Project Risk Management, Activity: L The risk register The **Process 1** Reliability requirements 1. Constraints, if required 2. Requirements for production availability on a system level

	Life cycle phase
	All phases
Production assurance Activities	Reliability assurance (management and demonstration) comprises planning; reporting and follow up of the production assurance activities and shall be performed for all the project phases. *Planning of the production assurance process* A Production Assurance Programme (PAP) shall be established and updated for a delivery project. The required content of this is the Production assurance performance objectives, Organisation and responsibilities and Activity schedule, ref. annex A. The core of the production assurance program defines the required activities to comply with the constraints (see figure 3) and the production availability objective. I.e. this activity requires scheduling of the tabulated production assurance activities for the relevant risk level and project phases. The reliability activities shall be performed in a timely manner to support decisions before they are made. *The required documentation of the production assurance includes:* 1. Production Assurance Programme (PAP) and the activities listed therein. Only the status and reference to documentation for the scheduled PAP activities is updated in PAP updates in later project phases. 1.1. Document the fulfilment of the reliability requirements. The reliability activities shall be reported to enable the decision makers to visit the background for the given advices. 1.2. Include references to documentary evidence of fulfilment of the reliability requirements according to 1, 2 and 3 in the PAP. 2. Reference to the risk register. All mitigating actions arising from the reliability program shall be transferred to the risk register for follow up and close out. 3. Document a statement of compliance of the reliability requirement in 1, 2 and 3. *Follow up of the production assurance process* A follow up system for the production assurance shall be applied to ensure progress of the PAP activities and the actions from this that are transferred into a risk register.
Output	• The asset development production assurance program shall be issued by operator in conceptual design phase. • The assurance program for each main supplier's scope of work shall be issued in the engineering phase, and updated prior to operation. • **Process: 5 Project Risk Management, Activity: L The risk register -** Close out of the risk register prior to operation. It is optional to include this in the PAP. • Document a statement of compliance of the reliability requirement in 1, 2 and 3. It is optional to include this in the PAP.

5.5 Process 4: Reliability Verification and Validation

The main objective of this process is to ensure that the implemented reliability performance is in compliance with the requirements in the production assurance plan. The production assurance verification and validation process has an important interface towards the design review and other technical verification activities in the sense that production assurance aspects should be addressed in the review. However, the design review process itself is normally the responsibility of engineering departments.

Table 5.5-1: Description of production assurance process 4 - Reliability verification and validation

	Life cycle phase
	Phase 1, 2 and 3 (Installation and Commissioning, and Operation is covered in Process 7)
Objective	To ensure that the implemented reliability performance is in compliance with the requirements in the PAP.
Input	Reliability process 3 Reliability Assurance, Activity H Planning: The timing of the Reliability Verification and Validation process is given in the reliability activity and process tables. Activity: I Reporting (Documentation of the complete production assurance.) Reliability process 5: Project Risk Management, Activity: L Risk register

	Life cycle phase
	Phase 1, 2 and 3 (Installation and Commissioning, and Operation is covered in Process 7)
Production assurance Activities	The reliability verification 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 reliability validation comprises a final check of the implemented reliability 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. *ISO 9000 series compliance is regarded as equal fulfilment of this activity.*
Output	PAP updates including ref. to the closed out activities and actions in the risk register.

5.6 Process 7: Performance tracking and analysis

This process covers the complementary parts of process 4 (Reliability verification and validation) in the sense that it represents the “verification” and “validation” of the production assurance performance in operation.

Table 5.6-1: : Description of production assurance process 7 - Performance tracing and analysis

	Life cycle phase	
	Installation and commissioning	**Operation**
Objective	Prepare for collection and analysis of performance data.	Collect and analyse operational performance data to identify potential 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 start of performance tracking (data collection) and analysis. Reference is made to ISO 14224 for performance data tracking and analysis requirements. Furthermore, collection of performance data related 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.
Link to other activities	None defined	Process 10 – Reliability improvement and risk reduction
Output	• Inventory models • Installation performance data	• Operational performance data • Input to reliability improvement processes

5.7 Process 10: Reliability improvement and risk reduction

Systematic identification of potentials for reliability improvement and risk reduction should be performed in all life cycle phases, except the feasibility and procure phase where this process is considered less relevant. Identification of improvement potentials should be based on observed in-service performance data and analyses.

Table 5.7-1: Description of production assurance process 10 - Reliability improvement and risk reduction

	Life cycle phase
	All (except feasibility & procurement)
Objective	The objective of this process is twofold: 1. Identify the need for improved system reliability performance or reduced risk is a project to ensure that performance goals are not compromised 2. 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.

	Life cycle phase
	All (except feasibility & procurement)
Input	• Performance data • Reliability analysis results • Production availability results • Risk identification results
Production assurance Activities	The specific production assurance and reliability management activities related to this process is performed within other processes as listed in the table row below. Hence, the only additional activity which should be performed for this process is related to communicate potential reliability improvement or risk reduction requirements or proposals to the right instance.
Link to other activities	• Risk and reliability in design activities • Reliability assurance • Project risk management • Performance tracking and analysis
Output	• Reliability improvement or risk reduction proposals

6 Interacting processes to production assurance

6.1 Introduction

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

6.2 Process 5: Project risk management

All mitigating actions arising from the production assurance program shall 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.

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

Table 6.2-1: Description of interacting process 5 - Project risk management

	Life cycle phase
	All phases
Objective	The objective of project risk management is to ensure that all risk elements that could jeopardise a successful execution and completion of the project are identified and controlled/mitigated in a timely manner.
Input	Transferred action items from all the production assurance processes.
Activities	Follow up and close out of all actions transferred from the production assurance processes
Output	Risk register

6.3 Process 6: Reliability and qualification testing

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

Table 6.3-1: Description of interacting process 6 - Reliability and qualification testing

	Life cycle phase		
	Conceptual design	Engineering	Procurement and fabrication
Objective	Identify the technology items requiring qualification testing by novelty scoring.	Ensure that acceptable robustness against dominating failure modes for critical technology items is demonstrated through the	Ensure that acceptable robustness against dominating failure modes for critical technology items is demonstrated through the

	Life cycle phase		
	Conceptual design	Engineering	Procurement and fabrication
		qualification test program.	qualification test program.
Input	Scope of supply Design Basis	Activity: B Equipment Reliability Analysis and C Production availability analysis. The reliability processes shall identify the relevant failure modes for the technology items to be tested and communicate this to the engineering organisation through the risk register, which is responsible for establishing the test program.	Activity: B Equipment Reliability Analysis and C Production availability analysis. The reliability processes shall identify the relevant failure modes for the technology items to be tested and communicate this to the engineering organisation through the risk register, which is responsible for establishing the test program.
Activities	Identifying the technology items requiring qualification testing	Establish Qualification procedures Perform testing Establish Qualification test reports	Establish Qualification procedures Perform testing Establish Qualification test reports
Output	Listing of technology items requiring qualification testing.	The engineering organisation should communicate the test results to the production assurance discipline, with respect to the relevant failure modes.	The engineering organisation should communicate the test results to the production assurance discipline, with respect to the relevant failure modes.

6.4 Process 8: Supply chain management

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

Table 6.4-1: Description of interacting process 8 – Supply chain management

	Life cycle phase
	Procurement
Objective	Ensure that manufacturers at each level of the supply chain understand what reliability is required and take appropriate actions to increase the probability that the specified reliability can be achieved
Input	Reliability requirements from the production assurance discipline.
Activities	Ensure that production assurance requirements (e.g. reliability requirements) flow down into the supply chain.
Output	Distributed reliability requirements for the supply chain

6.5 Process 9: Management of change

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 reliability performance 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 may 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 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.

Table 6.5-1: Description of interacting process 9 – Management of change

	Life cycle phase **All life cycle phases (except Feasibility)**
Objective	To ensure that no changes compromise the reliability performance requirements.
Input	• Reliability requirements • Description of the change
Activities	Process 2 – Risk and reliability in design • Design reviews
Link to other activities	• Supply chain management • Interface management • Quality assurance and control
Output	• Input to or update of the risk register • Performance impact assessments resulting from changes • Initiate the Equipment reliability- and/or production availability analysis

6.6 Process 11: Organisational learning

The purpose of the interacting process “organisation learning” in a production assurance perspective should be to communicate lessons learnt related to reliability and production performance from previous asset development projects to reduce the likelihood that product and process failure of the past in not repeated. The process is considered relevant for all life cycle phases.

Table 6.6-1: Description of production assurance process 11 - Organisational learning

	Life cycle phase **All life cycle phases**
Objective	To ensure that product and process failures of the past is not repeated.
Input	• Lessons learnt during projects • Performance data

	Life cycle phase All life cycle phases
Production assurance Activities	The responsibility of the production assurance and reliability management function in projects is to participate in lessons learnt reviews and other relevant experience transfer reviews. Furthermore, relevant lessons learnt in one project should be transferred into future projects.
Link to other activities	• Reliability assurance • Project risk management
Output	Input to: • Lessons learnt reviews • Risk register

7 Production assurance analyses

7.1 General requirements

Production assurance analyses shall be planned, executed, used and updated in a controlled and organised manner according to plans outlined in the PAP.

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

Production assurance analyses shall be consistent and assumptions and reliability data traceable. Analysis tools and calculation models are under constant development, and only data, models and computer codes accepted by the involved parties shall be used.

Requirements given in this section apply to production assurance analyses of complete installations, but will also apply to reliability and availability analyses of components/systems with obvious modifications.

7.2 Planning

7.2.1 Objectives

The objectives of the analyses shall 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

- identify operational conditions or equipment units critical to production assurance;
- predict production availability, deliverability, availability, reliability, etc;
- compare alternatives with respect to different production assurance aspects;
- identify technical and operational measures for performance improvement;
- enable selection of facilities, systems, equipment, configuration and capacities based on LCC methodology;
- provide input to other activities such as risk analyses or maintenance and spare parts planning;
- verify production assurance objectives or requirements.

7.2.2 Organisation of work

A working group shall be set up for conducting the analysis. This group shall have knowledge of methods used in production assurance analysis and should be acquainted with the system to be assessed. The working group may be supplemented with experts who have detailed knowledge of the system or operation in question, or of other disciplinary fields. Since production assurance analysis is a multi-disciplinary activity, close co-operation with other relevant disciplines is mandatory.

7.2.3 Content and scope

The system to be analysed shall be defined, with necessary boundaries towards its surroundings. An analysis of a complete production chain may cover reservoir delivery, wells, process and utilities, product storage, re-injection, export and tanker shuttling.

Operating modes to be included in the analysis shall 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 may also be relevant to consider testing, maintenance and emergency situations. The operating phase or period of time to be analysed shall also be defined.

The performance measures to be predicted shall be defined. In production availability and deliverability predictions, a reference level shall be selected which will provide the desired basis for decision-making. It shall also be decided whether to include the production performance effect from revision shutdowns as well as those catastrophic events normally identified and assessed with respect to safety in risk analyses.

The analysis methodology to be used shall be decided on the basis of study objectives and the performance measures to be predicted.

7.3 Execution

7.3.1 Technical review

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

7.3.2 Study basis

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

The system description shall describe, or refer to documentation of, all technical and operational aspects that are considered to influence on the results of the production assurance analysis and that are required to identify the system subject to the analysis. Such information may relate to production profiles or equipment capacities.

Reliability data shall be documented. A reference to the data source shall be included. Engineering or expert judgement can be referred to, but historically based data estimation shall be used if this can be accomplished. Regarding collection and use of reliability data, reference is made to ch clause 6.

The basis for quantification of reliability input data shall be readily available statistics and system/component reliability data, results from studies of similar systems or expert/engineering judgement. REGOP sessions can be used to predict plant specific downtimes. In the analysis the approach taken for reliability data selection and qualification shall be specified and agreed upon by the involved parties. Reference is also made to 6.2.

7.3.3 Model development

Model development includes the following activities:

- functional breakdown of the system;
- evaluation of the consequence of failure, maintenance, etc. for the various subparts;
- evaluation of events to be included in the model including common cause failures;

- evaluation of the effect of compensating measures if relevant;
- model development and documentation.

7.3.4 Input information

Check list of production assurance analysis information required to undertake analysis (e.g. design basis, P&ID, PFD, O&M strategies, reliability data, maintainability data, equipment criticality information, C&E matrices, production profiles, etc).

7.3.5 Analysis and assessment

7.3.5.1 Performance measures

To evaluate the performance of the analysis object, different performance measures can be used. Production availability and deliverability (whenever relevant) are the most frequently used measures. Depending on the objectives of the production assurance analysis, the project phase and the framework conditions for the project, the following additional performance measures can be used:

- the proportion of time production (delivery) is above demand (demand availability);
- the proportion of time production (delivery) is above zero (on-stream availability);
- number of times the production (delivery) is below demand;
- number of times the production (delivery) is below a specified level for a certain period of time;
- number of days with a certain production loss;
- resource consumption for repairs;
- availability of systems/subsystems.

As predictor for the performance measure, the expected (mean) value should be used. The uncertainty related to this prediction shall be discussed and if possible quantified. See 7.3.8

Annex D provides a guide on the elements to be included in the performance measure for predictions and for historical performance reporting.

7.3.5.2 Sensitivity analyses

Sensitivity analyses should be considered in order to evaluate the effect on results from issues such as alternative assumptions, variations in failure and repair data or alternative system configurations.

7.3.5.3 Importance measures

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

For conventional reliability analysis methods such as FTA, relevant reliability importance measures as found in literature can be used.

When production availability or deliverability is predicted, importance measures can be defined by the contribution to production unavailability from each item/event. In order to take account of the effects of compensating measures, it may be required to establish the criticality list based on successive sensitivity analyses where the contribution from each event is set to zero.

7.3.6 Reporting

The various steps in the analysis as described above shall be reported. All assumptions shall be reported.

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

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

7.3.7 Catastrophic events

Some serious, infrequent events will cause long-term shutdown of production. These events are classified as catastrophic, and shall be distinguished from the more frequent events which are considered in analyses of production availability and deliverability. The expected value contribution from a catastrophic event is normally a rather small quantity, which is an unrepresentative contribution to the production loss. If the catastrophic event occurs, the actual loss would be large and this could mean a dramatic reduction in the production availability or deliverability.

The consequences for production as a result of accidents in production and transportation systems are normally considered in the risk analysis. The results from the risk analysis may be included in the production assurance analysis report in order to show all production loss contributors.

Additional guidance is given in Annex D.

7.3.8 Handling of uncertainty

The uncertainty related to the value of the predicted performance measure shall be discussed and if possible quantified. The quantification may have the form of the uncertainty distribution being the basis for the expected value of 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 shall be identified and discussed. Also factors contributing to uncertainty as a result of the way system performance is modelled, shall be covered.

Importance and sensitivity analyses may be carried out to describe the sensitivity of the input data used and the assumptions made.

Additional guidance is given in Annex E.

8 Reliability and performance data

8.1 Collection of reliability data

8.1.1 General

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

- product design;
- current product improvement;

- establishing and calibrating maintenance programme and spare parts programme;
- condition based maintenance;
- identifying contributing factors to production unavailability;
- improving confidence in predictions used for decision support.

8.1.2 Equipment boundary and hierarchy definition

Clear boundary description is imperative, and a strict hierarchy system shall be applied.

Boundaries and equipment hierarchy shall be defined according to ISO 14224. Major data categories are defined as follows:

- **installation part:** Description of installation from which reliability data are collected;
- **inventory part:** Technical description plus operating and environmental conditions;
- **failure part:** Failure event information such as failure mode, severity, failure cause, etc;
- **maintenance part:** Corrective maintenance information associated with failure events, and planned or executed preventive maintenance event information.

8.1.3 Data analysis

To predict the time to failure (or repair) of an item, a probability model shall be determined. The type of model depends on the purpose of the analysis. An exponential lifetime distribution may be appropriate. If a trend is to be reflected, a model allowing time-dependent failure rate shall be used.

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

8.2 Qualification and application of reliability data

The establishment of correct and relevant reliability data (i.e. failure and associated repair/downtime data) requires a data qualification process which involves conscious attention to original source of data, interpretation of any available statistics and estimation method for analysis usage. Selection of data shall be based on the following principles:

- data should originate from the same type of equipment;
- data should originate from equipment using similar technology;
- data should if possible originate from identical equipment models;
- data should originate from periods of stable operation, although first year start-up problems should be given due consideration;
- data should if possible originate from equipment which has been exposed to comparable operating and maintenance conditions;
- the basis for the data used should be sufficiently extensive;
- the amount of inventories and failure events used to estimate or predict reliability parameters should be sufficiently large to avoid bias resulting from 'outliers';

- the repair and downtime data should reflect site specific conditions;
- the equipment boundary for originating data source and analysis element should match as far as possible. Study assumptions should otherwise be given;
- population data (e.g. operating time, observation period) should be indicated to reflect statistical significance (uncertainty related to estimates and predictions) and "technology window";
- data sources shall be quoted.

Data from event databases (e.g. OREDA® database) provide relevant basis for meeting the requirements above. In case of scarce data, proper engineering judgement is needed and sensitivity analysis of input data should be done.

Reliability data management and co-ordination are needed to ensure reliability data collection for selected equipment and consistent use of reliability data in the various analyses.

8.3 Performance data

Production performance at facility/installation level shall be reported in a way that enables systematic production assurance to be carried out. The type of installation and operation will determine the format and structure of performance reporting. Annex C outlines type of events to be covered for a production facility. Relationship between facility performance data and critical equipment reliability data is needed. Assessment of actual performance shall be carried out by installation operator on a periodic basis, in order to identify specific trends and issues requiring follow-up. 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 to earlier performance predictions should be done, thereby gaining experience and provide feedback to future and/or other similar performance predictions.

9 Performance objectives and requirements in contracts

9.1 General

The following clauses give requirements to the specification of production assurance objectives and requirements. The specification of production assurance objectives and requirements can be considered for system design, engineering and purchase of equipment as well as operation in defined life cycle periods.

In this respect also IEC 60300-3-4, Part 3, Section 4, [7] should be considered.

9.2 Specifying production assurance

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

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

When specifying production assurance requirements it is important to state the following:

- limitations and boundaries;
- application of the system;

- definition of a fault;
- definition of the period of time for which the production assurance requirements applies (e.g. from first oil and to the end of design life)
- operating conditions and strategies;
- environmental conditions;
- maintenance conditions and strategies;
- methods intended to be applied for the verification of compliance with the production assurance requirements;
- If numerical production assurance requirements are specified, the corresponding confidence levels should be specified.
- definition of non-conformance to the requirement;
- how non-conformance shall be handled.

Quantitative requirements may be expressed based on performance measures such as:

- production availability;
- system availability;
- Survival probability or Minimum Failure Free Operating Period
- time to failure;
- time to repair;
- spare parts mobilisation times;

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.

9.3 Verification of requirement fulfilment

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

- field or laboratory testing;
- documented relevant field experience;
- analysis;
- field performance evaluation after delivery;

Data for calculation shall be based on recognised sources of data, results obtained from operational experience on similar equipment in the field or from laboratory tests. The reliability data shall be agreed between the supplier and the customer.

9.4 Co-operation between operator and supplier

In order to reduce the number of failures and downtime of products and systems, it is necessary for suppliers and operators to co-operate during all phases of the product/project life cycle. It should be specified that the operator acknowledge the responsibility to monitor performance and reliability in use and exchange field experience with their suppliers.

Annex A
(informative)

Contents of production assurance programme (PAP)

A PAP should cover the topics given by the following standard table of contents:

Title:

Production assurance programme (PAP) for “installation/facility/system/operation” (to be specified)

1. Introduction

1.1 Purpose and scope

1.2 System boundaries and life cycle status

1.3 Revision control

Note: Major changes since last update to be given

1.4 Distribution

Note: Depending on the content, all or parts of the PAP are distributed to parties defined.

2. Production assurance philosophy and performance objectives

2.1 Description of overall optimisation criteria

2.2 Definition of performance objectives and requirements

Note: Relevant reference to regularity targets, objectives and requirements in contract documents. Separate documents may further specify the targets, objectives and requirements. Reference is made to the loss categories and battery limits to define what is included and what is excluded in the targets.

Note: This section should cover both corporate/company/project specific and regulatory/authority requirements.

2.3 Definition of performance measures

3. Organisation and responsibilities

3.1 Description of organisation and responsibilities

Note: Focusing on production performance and LCC, internal and external communication, responsibilities given to managers and key personnel, functions, disciplines, sub-projects, contractors, suppliers.

3.2 Action management

Note: A description of the action management system should be included, defining how recommendations and actions are communicated, evaluated and implemented.

3.3 Verification and validation functions

Note: Specify planned 3rd party verification activities related to production assurance/reliability (if any).

4. Activity schedule

4.1 Activity/life cycle phase - main overview

Note: A table similar to Table 1 can be included to indicate past and future production assurance, reliability and LCC activities.

4.2 Production assurance/reliability activities

Note: Production assurance activities that are planned to be carried out shall be listed with a schedule which refers to main project milestones and interfacing activities. The specific production assurance or reliability activity plans may exist as stand-alone documents which can be quoted.

Note: The relationship between the various activities should be clearly stated in the programme (input/output relationship, timing etc.)

5. References

Note: References to key project documentation.

Annex B
(informative)

Outline of techniques

B.1 General

Reliability and availability analyses are systematic evaluations and calculations which are carried out to assess the performance of a system. The system may, for example, be a production or transportation system, a compression train, a pump, a process shutdown system or a valve. Production assurance analyses are part of a production assurance programme. The term "production assurance analysis" should be used for analysis of a total facility (e.g., offshore production system). The following can be used as a guide:

- production assurance analysis of installation(s), or operations;
- availability analysis of important systems;
- reliability and availability analysis of equipment/component;

Some relevant analysis methods and techniques are described briefly below. Reference is made to reliability analysis textbooks or referenced standards in the text for more detailed descriptions.

B.2 Failure modes and effects analysis (FMEA/FMECA)

Analysis description	Failure Mode and Effect Analysis (FMEA) / Failure Mode, Effect, and Criticality Analysis (FMECA) A FMEA is a technique for establishing the effects of potential failure modes within a system. The analysis can be performed at any level of assembly. This may be done with a criticality analysis, in which case it is called a FMECA. The latter is a quantitative analysis, where you need failure probability and consequence data to asses the criticality of each failure mode.
Objective of analysis	FMECA 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; depending on the focus the amount of data required is different (see next tables for details), While it is most often used in the early stages of the design process to improve the inherent reliability, the technique is equally useful in addressing system safety, availability, maintainability, or logistics support
Ref. to existing Standards	MIL-STD-1629 A – Military Standards: Procedures for performing a Failure Mode, Effects, and Criticality Analysis IEC 60812 (1987-05) – Analysis techniques for system reliability – Procedure for Failure and Effects Analysis (FMEA)

Overall need for info	The analysis is an inductive process in which individual failures are generalized into potential failure modes, The structured method consists of the following steps: System definition (both from functional and hardware standpoints) Identification of failure modes (it must include the operational and environmental conditions present when failure occurs) Determination of cause (understanding of failure mechanism, and identification of the lowest level in hierarchy affected) Assessment of effect (in terms of system performance, reliability, maintainability and safety) Identification of detection means (to verify that suitable detection means exist for all critical failure modes) Classifications of severity (to assign priorities to corrective actions; typically 3 or 4 levels) Estimation of probability of occurrence (based on experience or public data bases) Computation of criticality index (it combines the probability of occurrence and the severity of the failure) Determination of corrective action (by eliminating the cause of the failure, decreasing their probability of occurrence, or reducing the severity of the failure)

B.3 Fault tree analysis (FTA)

Analysis description	Fault Tree Analysis (FTA) This is a graphical top-down method used to analyse system reliability / availability
Objective of analysis	The objectives are rather numerous, e.g.: - build in a systematic a graphic which represent the combinations of the individual components failures which lead to the whole system failure and doing so that, obtain the Boolean equation linking the undesirable event (at the whole system level) to the failure of he individual components; - analyse qualitatively the reliability/availability of the system by finding and sort 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 impliquants" (non coherent FT); - analyse semi-quantitatively the reliability/availability of the system by sorting its minimal cut sets (or prime impliquant) by decreasing probabilities; - calculate the probability of failure (unreliability / unavailability) 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);

Ref. to existing Standards	IEC 61025 (1990-10) Fault Tree Analysis
Overall need for info	Basically a fault tree represents a boolean formula 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 pure probability of failures which must be evaluated from the reliability parameters of the related components : - probability of failure upon demand (γ) - failure rates (λ) - Repair rates (μ) - test interval (τ) - test efficiency - human error – etc. FTA is also a very good support for performing common cause failure analyses, sensitivity analyses and uncertainty analyses The fault tree can also be used in combination with cause-consequence diagram (CCD) to analyse underlying causes of the event failure

B.4 Reliability block diagram (RBD)

Analysis description	The application of Reliability block diagram (RBD) will be the same as for Fault Tree Analyses (FTA). In principle RBD can be used for predictions of production availability for a complete plant. A limitation is that partial failure of the system is not easily handled.
Objective of analysis	The purpose of the RBD technique is to represent failure and success criteria graphically and to use the resulting logic diagram to evaluate system reliability performance.
Ref. to existing Standards	IEC 61078 Reliability Block Diagram
Overall need for info	- failure rates (λ)

B.5 Production availability analysis - simulations

Monte-Carlo simulation is a technique in which the failures and repairs of a system are simulated by the use of random number generators which draw from a probability distribution. Before performing a Monte-Carlo simulation the reliability structure and the logic of the system being analysed has first to be modelled by a flow network/RBD or other techniques.

Monte-Carlo simulation is well suited for production availability prediction of a production facility. It 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.

B.6 Design reviews

Formal design reviews are normally carried out for many systems in the course of a development project. Special regularity design reviews should be considered, or regularity aspects should be included in other design reviews. Maintainability aspects may for example be included in working environment design reviews.

Design reviews should be performed by a group of persons from relevant disciplines. The design review should be performed with the systematic application of guide words or check lists.

Design reviews can focus on aspects influencing regularity such as

- general quality of products;
- product specifications;
- design margins/safety margins affecting reliability of equipment;
- system configuration/redundancy;
- operational conditions;
- maintenance philosophy;
- maintenance procedures;
- maintainability/access/modularisation;
- working environment for maintenance activities;
- required skills for maintenance personnel;
- spare parts availability;
- tools required;
- safety;
- product experience.

Ref. to existing standards:

- IEC 61160; Formal design review

B.7 Hazard and operability study (HAZOP)

The purpose of HAZOP studies is to identify hazards in process plants and to identify operational problems and provide essential input to process design. Being useful from a regularity point of view, the HAZOPs may also be used to identify safe alternative ways of operating the plant in an abnormal situation to avoid shutdown.

HAZOPs may be used on systems as well as operations. Used on operations, such as maintenance or intervention activity, findings from the HAZOP may provide input to regularity analyses.

Ref. to existing standards:

- IEC 61882; Hazard and operability studies (HAZOP studies)
- ISO 17776; Guidelines on tools and techniques for hazard identification and risk assessment

B.8 Performance and operability review (POP)

POP denotes a thorough review of failure and downtime scenarios in the production system to be analysed. The objectives with the review may be to

- evaluate how failures in the system are identified and which consequences the various failure modes imply;
- estimate the downtime related to preparation for repair and start-up of production (focus on process related conditions that may affect these issues); this shall be seen in conjunction with reliability data qualification and suggested estimates which can be assessed in a POP exercise;
- evaluate preliminary reliability data for a production availability model.

The total downtime related to restoration of a failed item consists of several phases. These are:

- pre-repair phase (e.g., troubleshooting, isolation, depressurisation, gas freeing, mechanical pre-work);
- active repair time (typically called MTTR);
- post repair phase (e.g., mechanical post-work, start-up).

A POP group is established consisting of regularity analysts and disciplines like process operation and maintenance. During POP sessions, failure scenarios of each sub-part or stage of the model are evaluated through a systematic review. Total downtime estimates are established by achieving time estimates for all downtime phases.

An illustration of downtime associated with a failure event is shown in Figure B.1.

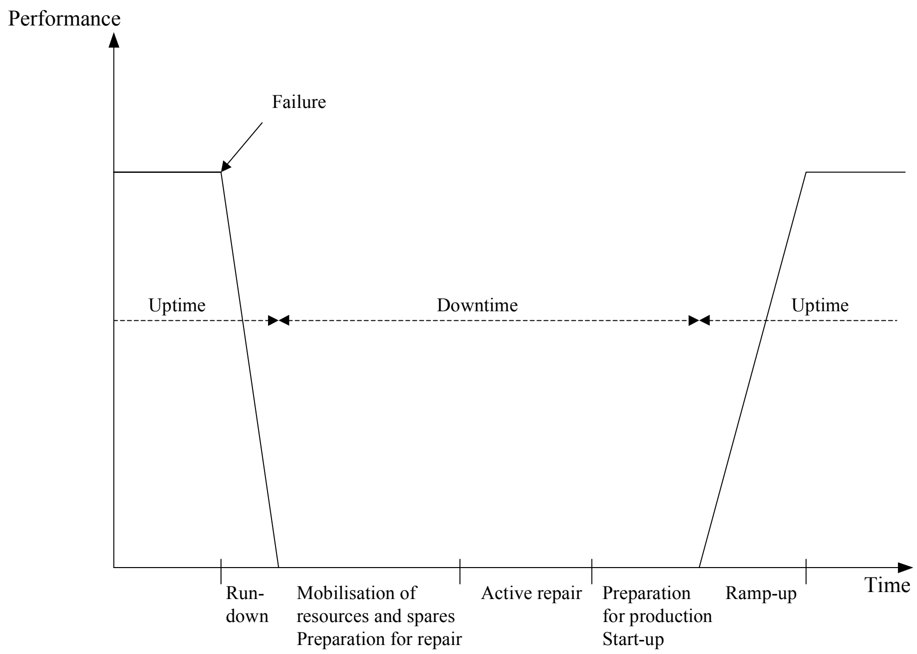

Figure B.1 — Illustration of downtime associated with a failure event

B.9 Reliability testing

Several types of reliability testing can be performed in order to predict reliability of components.

In accordance with BS 5760, Part 2 [6], tests may include

- reliability growth testing;
- development reliability demonstration testing;
- environmental stress screening, including burn-in, during production;
- production reliability assurance testing;
- in service reliability demonstration.

It should be noted that reliability testing is not applicable for most components, sub-systems and systems in the petroleum, petrochemical and natural gas industries. Accelerated life time testing involves overstressing in terms of environmental and operational conditions, which provokes different or alternative failure modes and degradation mechanisms compared to normal operating conditions. I.e. it has proved extremely challenging to reproduce normal lifetime degradation from accelerated life time testing.

B.10 Human factors

Interfaces between the product, systems, equipment (including its operations and maintenance documentation) and its operation and maintenance personnel should be analysed to identify the potential for, and the effects of, human errors in terms of product fault modes. Particular attention should be given to the following:

- the analysis of the product to ensure that the human interface, and related human tasks, are identified;
- the evaluation of potential human mistakes at the interface during operation and maintenance, their causes and consequences;
- the initiation of product and/or procedure modifications to reduce the possibility of mistakes and their consequences.

Reference to relevant literature:

- *Alarm systems, a guide to design, management and procurement*; Engineering Equipment & Materials Users Association (EEMUA) Publication No 191.
- *Process plant control desks utilizing human-computer interface: a guide to design, operational and human interface issues*; Engineering Equipment & Materials Users Association (EEMUA) Publication 201: 2002

B.11 Software reliability

Software systems are likely to contain faults due to human error in design and development, and these faults can give rise to failures during operation. The improved reliability of hardware components, and of electronic components in particular, can reduce the contribution of hardware unreliability to system failure. Hence systematic failures due to software faults may frequently become the predominant cause of failure in programmable systems.

In analysing a system containing software components, the block diagram technique, FME(C)A, and FTA can all be applied to take account of the effects of software failure on system behaviour. This is useful for detecting software components that are critical to the function of the system. For these methods to be applied quantitatively, the reliability of the software components has to be measured.

Note that software systems are special in the manner faults occur, as listed below:

- the faults are latent within the software from the start and are hidden;
- all software which is identical have the same faults;
- once a fault is detected and successfully repaired, it will not occur again;
- extensive testing will eliminate many software faults;
- software shall be developed, designed, tested and used with the same kind of hardware. (i.e., change of hardware may activate latent faults within the software).

B.12 Common cause modelling

The classical formulae used to calculate system reliability from component reliability assume that the failures are independent. Some common cause failures can occur that lead to system performance degradation or failure through simultaneous deficiency in several system components due to internal or external causes. External causes can include human or environmental problems while internal causes are generally associated with hardware.

Regularity predictions should include an evaluation of common cause failures.

B.13 Life data analysis

Life data analysis is used to analyse life data (failure data) to fit the data to a particular distribution. It is then possible to use the known characteristics of the distribution to gain a more complete understanding of the failure behaviour of the item. One or more of the many available distributions may be suitable to model a particular data set.

NOTE The choice of the most appropriate distribution usually requires prior knowledge of the failure regime that is expected to apply).

B.14 Reliability centred maintenance analysis (RCM)

In a RCM analysis which has the purpose to establish the (preventive) maintenance programme in a systematic way, the following steps are normally covered:

- functionality analysis – definition of the main functions of the system/equipment;
- criticality analysis – definition of the failure modes of the equipment and their frequency FMECA may be used to a larger or minor degree;
- identification of failure causes and mechanism for the critical fault modes;
- definition of type of maintenance based on criticality of the failure, the failure probability, the maintenance cost, etc.

The RCM process shall be updated throughout the life cycle for necessary revision of the maintenance programme, also using relevant field experience data as well as verifying criticality assessment.

Valid production assurance analysis information used in early project phases should be fed into the RCM process when appropriate, to enable consistency and interaction between the two studies. Co-ordination of reliability data utilised in the two studies shall be ensured. Similarly, the 'living' RCM study information should be consulted when production assurance and reliability analyses are updated during operational stages.

B.15 Risk based inspection analysis (RBI)

RBI is a methodology which aims at establishing an inspection programme based on the aspects of probability and consequence of a failure. The methodology combines production assurance and risk analysis work and is typically applied for static process equipment (e.g., piping, pressure vessels and valve bodies). The failure mode of concern is normally loss of containment.

Interactions between RBI, RCM, production assurance, availability and risk analyses are important to ensure consistency in relevant failure rates and associated downtime pattern for equipment covered in these analyses. Experiences of RBI undertaken in the operating phases may also be utilised in connection with production assurance analysis of design alternatives in the planning stages as well as in early maintenance planning.

B.16 Test interval optimisation

In order to comply with acceptance criteria and/or more specific requirements for (e.g., safety systems) testing at certain intervals are necessary. Based on a system analysis, the test interval for both components and the system in general may be optimised with respect to the specified acceptance criteria/requirement and cost of testing. The component condition after testing (i.e., good-as-new or bad-as-old) should be clearly stated. Frequent testing will normally lead to a high safety availability when the test coverage is adequate (by test coverage is meant the relevance of the tests (i.e., the likelihood of revealing a hidden functional failure during a test). Testing may, however, be expensive and may also in specific cases deteriorate the system (e.g., pressure testing of valves) and even introduce additional failures to the system. The test interval should be optimised based on an iterative process where the overall system acceptance criteria and costs are among the optimisation criteria.

B.17 Spare parts optimisation

Analysis description	Spare part optimisation is based on operational research and selected reliability methods and may be analytical, or use Monte-Carlo simulations. The optimisation process aims at balancing the cost of holding spare parts against the probability and cost of spare part shortage.
Objective of analysis	Optimize spare parts storage in terms of: • initial quantity of spare parts • reorder point • replenishment quantity • stock allocation (nominal)
Ref. to existing standards	IEC 60300-3-12 IEC 60706-4

Overall need for info	The following data are needed: • demand rates, unit prices and criticality for defined spare parts • work breakdown structure (configuration) • turn around times, repair fractions, lead times • supply links, transportation times, storage and re-supply costs

B.18 Methods of structural reliability analysis (SRA)

The methods of SRA represent a tool for calculating system probabilities where “system failure” is formulated by means of the so-called limit state function and of a set of random variables called the basic variables. The basic variables represent causal mechanisms related to load and strength that can give rise to the “system failure” event. The limit function is based on physical models. Methods of SRA are used to calculate the probability, and to study the sensitivity of the failure probability to variations of the parameters in the problem. Often Monte-Carlo simulation is used, but this is a very time consuming technique in cases of small probabilities.

Methods of SRA are tools for calculating probability. Thus the models used in this type of analysis are standing in line with other reliability models, like lifetime models for mechanic and electronic equipment, reliability models for software, availability models for supply systems and models for calculating the reliability of human actions. All models of this kind can be used to calculate single probabilities that are inputs in different methods used in risk and regularity analyses such as for the basic events in fault tree and RBD analysis. A special feature of methods of SRA is, however, that the influence from several random variables and failure modes may be taken into account in a single analysis. Thus, using methods of SRA, the splitting of events into detailed sub events is often not necessary to the same extent as in for example FTA.

B.19 Life cycle cost analysis (LCC)

Production assurance predictions are an important input parameter to LCC evaluations. LCC evaluations are normally performed to select between two or more alternatives. The evaluations may include parts or the whole facilities. The format of the regularity input shall be suitable to calculate the LOSTREV as part of the production assurance analysis, whilst CAPEX and OPEX are normally covered in the overall LCC analysis. One should recognise that OPEX includes the corrective maintenance cost (workload, spares, logistics and other resource consumption) which can be estimated from the production assurance analysis outlined in this standard.

Each alternative shall be presented with the appropriate production performance measures as a percentage of planned production. If production performance varies with time, performance measures shall be presented as a function of time (one figure for each year of the field life). The related reference level profile shall also be presented so that the production loss and hence, the LOSTREV can easily be calculated. An important assumption that needs to be clarified in each case is if, and when, the production loss can be recovered.

Unless the LCC evaluations aim at predicting the total LCC, the production performance input may be limited to the differences between the alternatives. The production performance input shall include relevant figures for oil production, gas export and other as required.

Ref. to existing standards:

- ISO 15663, part 1-3; Life cycle costing

B.20 Risk and emergency preparedness analysis

Risk and emergency preparedness analyses link many aspects of reliability and production assurance, and safety and environmental issues. Specifically the interfaces to a risk and emergency preparedness analysis are as follows:

- input to the risk and emergency preparedness analysis in terms of reliability of safety systems (fire water system, fire and gas detection system, ESD system). Such individual system analyses may be a part of the overall production assurance analysis;
- the risk and emergency preparedness analysis may impose reliability requirements on certain equipment, typically safety systems;
- the risk and emergency preparedness analysis may impose requirements to equipment configuration that will affect production assurance;
- production unavailability due to catastrophic events (see 7.3.7 and annex E);
- as the production assurance analyses address and quantify operational and maintenance strategies, such strategies may also affect risk and emergency preparedness analysis assumptions and predictions. Examples are manning levels, logistics and equipment test strategies;
- co-ordination of study assumptions and data in risk and emergency preparedness analyses and production assurance analyses is recommended.

B.21 Novelty scoring analysis

Equipment to be qualified can be classified according to: (i) the newness of the technology, and (ii) the amount of experience from previous application of a similar technology in the actual operational and environmental context. The DNV RP-A203 applies the classification illustrated in Table 1, where the technology is classified into four categories:

1. No new technical uncertainties
2. New technical uncertainties
3. New technical challenges
4. Demanding new technical challenges

Table B1: Classification of the new technology

Application area	Technology		
	Proven	Limited field history	New or unproven
Known	1	2	3
New	2	3	4

This classification applies to the system level as well as to each separate part and function. The classification is used to highlight which parts and functions that have to be carefully scrutinized in the development process.

Technology in category 1 is proven technology where proven methods for qualification, testing, calculations, and analysis can be used to document compliance with requirements. Technology defined as categories 2-4 is defined as new technology.

Annex C
(informative)

Performance measures

Performance measures are used both in analyses for prediction and for reporting of historical performance in the operational phase. The performance measures will include the effect of downtime caused by a number of different events. It is imperative to specify in detail the different type of events and whether they shall 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. Detailed production reporting system will exist, but should enable comparable/exchangeable field reporting as indicated below.

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

- production availability of oil into storage/for export;
- availability of water injection (time based) or water injection availability (volume based);
- availability of gas injection (time based) or gas injection availability (volume based);
- production availability of gas for export measured at the exit of the process facility;
- deliverability of gas export measured at the delivery point and including the effect of compensating measures;
- production availability of the subsea installation in isolation without considering downstream elements;
- availability of the process facilities in isolation.

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

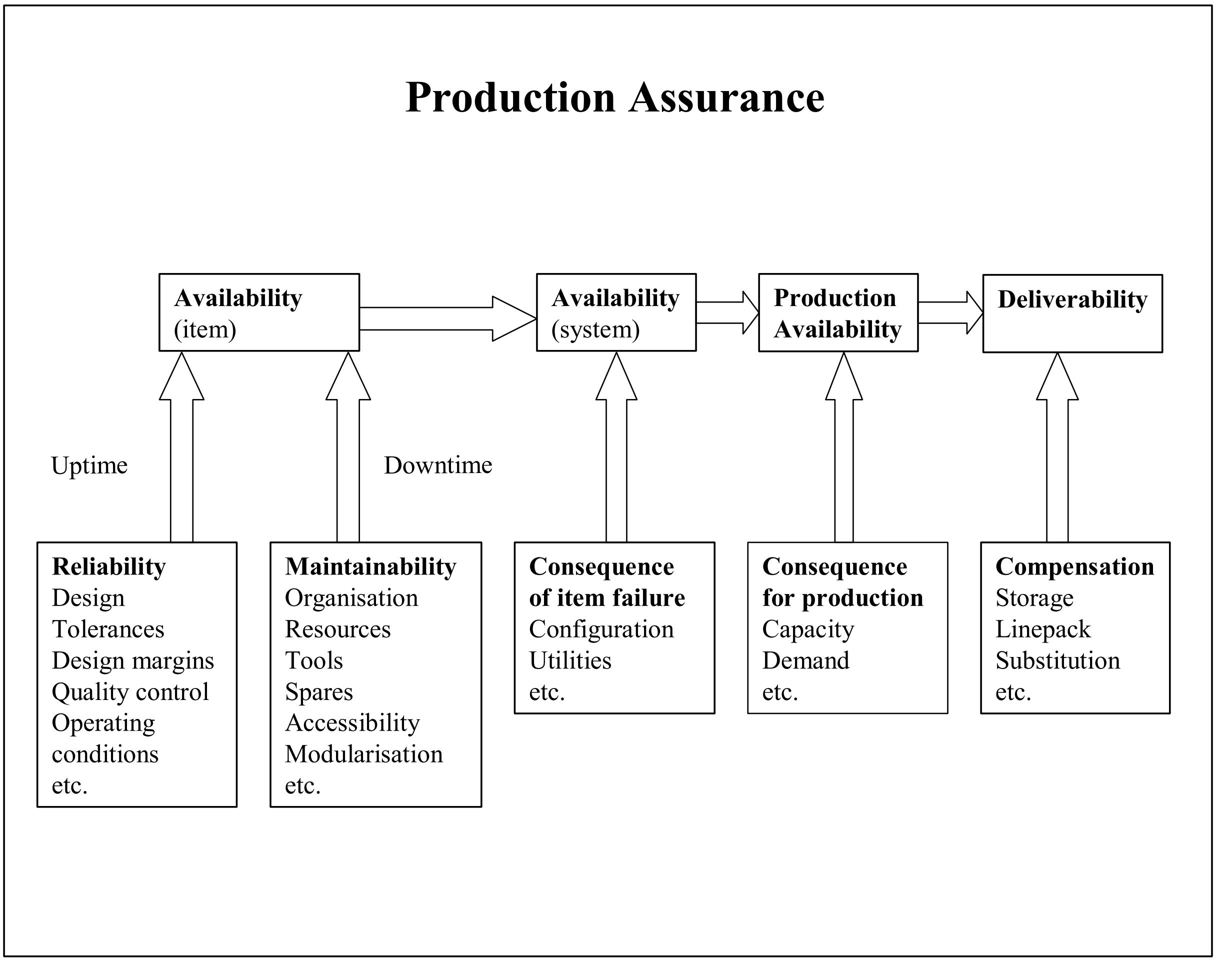

Figure C.1 - illustration of relationship between some production assurance terms

Production availability (and deliverability) is a volume based performance measure which is defined as follows:

Production availability = Produced volume (Sm^3) / Reference level (Sm^3)

The reference level needs to be defined if these measures shall be predicted or reported. Ideally, the same reference level as used in production availability analyses shall be used also when reporting historical production availability during the operational phase. Some alternatives are discussed in the following:

contracted volume;
If there is a sales contract, the contracted volume will be a preferred reference level. The contracted volume may be specified with seasonal variations (swing). In that case the swing profile should be used as a reference level. The contracted volume may also be specified as an average over a period of time and where the buyer nominates the daily supplies some time in advance. Reporting historical production availability or deliverability, the reference level volume should be the actual nominated volumes. 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.

design capacity;
The design capacity of the facility could be used as a reference level. This could be an appropriate reference level if only a part of the production chain, e.g. a process facility, is subject to analysis. The design capacity is

easily available in an early project phase. A limitation is that production may be restricted by factors outside the system boundaries (e.g. well potentials) which may lead to misleading conclusions.

well production potential;
The well production potential can be a reference level if it is less than the design capacity. Especially in the production decline period this will be the case. It should be kept in mind that reservoir simulations are associated with uncertainty. The well production potential may be adjusted during the operating phase.

planned production volume assuming no downtime;
This will be the maximum production volume given the constraints of design capacities and well production potentials assuming that there will be no downtime. This will be the preferred reference level in production availability predictions. 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.

planned production volume.
The planned production volume when expected downtime is considered can be used as a reference level when reporting historical production availability in the operational phase. If less than average downtime occur in a period, the performance measure will be greater than 100%. The disadvantage of using this reference level is that the costs of downtime will be concealed.

In addition to the volume based performance measures, time based measures can be used:

Availability = Uptime (h) / Observation period (h)

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

Table C.1 provides guidance on the events that should be included in production availability predictions and reporting of historical production availability for a production system (i.e., volume-based performance measures). Time-based availability predictions or statistics can apply same event categorisation. Event categorisation for other specific operations (e.g. pipelaying) and its associated system/equipment will typically have another format which needs to be specified as required. Battery limits for the facilities shall be clearly defined, also with regards to any third party processing, tie-ins, subsea installations, etc.

Table C.9.4-1 — Upstream events

	Type of event	Comments
A	**Wells (downhole and subsea/surface)** Surface Xmas tree	"Wells" covering everything from (and including) the tubing hanger and downwards to (and including) the reservoir
A1	Reservoir uncertainties	Production availability impact due to reservoir uncertainties (e.g. reservoir producing less than anticipated)
A2	Downhole equipment failure	Production availability impact until well intervention starts.
A3	Unplanned downhole well intervention (workover)	Production availability impact arising from repair of downhole failure. Including heavy lifts. Reliability based contingency preparedness is anticipated
A4	Downhole equipment testing & inspection/surveys	Figure 7 in ISO 14224 may be referenced (this applies to all entries dealing with inspection and other preventive maintenance activities)
A5	Planned well activities (drilling, completion, logging + planned well maintenance)	Production availability impact including heavy lifts which depends on simultaneous activity procedures.
A6	Well production testing & logging	The production loss caused by the need to undertake such testing. The production availability impact depends on test design and procedures.
A7	Well stimulation (scale squeeze, re-perforation, side tracking, acid wash, etc.)	The production downtime and loss caused by the activity shall be included. The positive effect on production rate should also be considered since this will influence the reference level for the performance measure.
A8	Flow assurance (Hydrates, etc)	
B	**Subsea**	
B1	Subsea equipment failure	Production availability impact until subsea intervention starts
B2	Unplanned subsea intervention	Production availability impact arising from repair of subsea failure, and may include downhole intervention. Reliability based contingency preparedness is anticipated Note: Assess combining B1 and B2
B3	Subsea equipment testing and inspection	
B4	Flow assurance, pigging	The production downtime and loss caused by the activity shall be included. The positive effect on production rate should also be considered since this will influence the reference level for the performance measure.
C	**Topside (process and utility)**	
C1	Equipment failure and repair (including failure of utility/ ancillary/auxiliary systems such as power, chemicals, etc.)	Production availability impact until corrective maintenance starts and the corrective maintenance itself may be split, if needed.
C2	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 which implies production.
C3	Spurious trips	Instrumentation failures and repair.
C4	Real trips including operator errors	Process upsets. Logistic delays included (e.g. on unmanned platform).
C5	Flow assurance	
D	**Export**	
D1	Offloading	These are shutdowns caused by (e.g. a full storage) offloading equipment failures or tanker not present.
D2	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the battery limits (third party issues)

	Type of event	Comments
D3	Flow assurance	
E	**Drilling**	
E1	Moving from one well to the next one	Activities carried out to remove the rig from one location to the next one, such as removing and re-installing anchor lines of floating rigs in offshore scenarios, others.
E2	Drilling well planned activities	Drilling, regular BOP and safety equipment related activities, logging/coring, orienting the well, running and cementing casings/liners activities and others.
E3	Rig downtime due to rig equipment failure, including accessories such as logging tools	Activities developed to repair a 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 repairing related activities.
E4	Rig downtime due to well problems	Combating a possible kick, fishing activities, re-setting or correcting the wellhead installation, reaming, re-drilling, working on a well unstable mechanically, adjusting drilling fluid parameters, correcting cement job, others.
E5	Waiting for something to proceed with drilling operations	Waiting on weather, on spare parts, operation definition, materials, others.
E6	Well formation test	Activities related to the evaluation of a possible reservoir in the well.
E7	Well abandonment and/or decommissioning	Setting temporary or definitive cement plug, setting a bridge plug, removal of equipment from the location and others.
F	**Intervention and workover**	
F1	Moving from one well to the next one	Activities carried out to remove the rig from one location to the next one.
F2	Intervention and workover planned activities	Checking or setting safety barriers in the well before intervention, regular BOP and safety equipment related activities, running/installing Christmas tree, gravel packer and tubing activities and others.
F3	Rig downtime due to rig equipment failure, including accessories such as logging tools	Activities developed to repair a 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 repairing related activities.
F4	Rig downtime due to well problems	Combating a possible kick, fishing activities, correcting the installation others.
F5	Waiting for something to proceed with drilling operations	Waiting on weather, on spare parts, operation definition, materials, others.
F6	Production test	Activities related to the evaluation of a reservoir.

	Type of event	Comments
F7	Well abandonment and/or decommissioning	Setting temporary or definitive cement plug, setting a bridge plug, removal of equipment from the location and others.
G	**Other**	
G1	Revision shutdowns	Can be considered to be excluded both in predictions and for historical reporting (e.g., when revision shutdowns are defined in sales contracts).
G2	Modifications (not equipment replacements – this term needs to be further defined)	Modifications which have impact on production availability and availability
G3	Bad weather	Trips and offloading events may be caused by bad weather.
G4	Accidental events	Safety related events. Downtime caused by events which are of catastrophic type, should be reported separately in predictions.
G5	Labour conflicts	Not to be included in predictions.
G6	Environmental policies (flaring, oil spill contingencies, etc)	
G7	Political restrictions	(OPEC, quotas)
G8	Out of product specification (below and above spec)	CO2, BS and W, etc.
G9	Security	Terrorism, riots, etc.

Table C.9.4-2 — Midstream events

	Type of event	Comments
A	**Pipeline**	Covers only line pipe, flanges, block valves, etc.
A1	Preventative maintenance	Losses associated with planned maintenance
A2	Planned testing /inspection / surveys	Losses arising from planned inspections, hydrostatic testing, inspection pigging, etc
A3	Unplanned activities and equipment failures	Production assurance 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
A4	Flow assurance	Flow assurance (Hydrates, etc) – flow assurance pigging plus failure of DRA
A5	Post modifications impact	Losses associated with modification work, i.e. Tie-ins
A6	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the battery limit of terminal (third party issues)
B	**Pump / Compressor station**	All equipment & activities within battery limit of pump / compressor station, includes process and utilities (power, chemicals, Instrument air, etc.)
B1	Preventative maintenance	Losses associated with planned activities – preventative

	Type of event	Comments
		maintenance
B2	Planned equipment testing /inspection / surveys	Includes equipment testing of safety equipment which implies lost production.
B3	Unplanned activities and equipment failures	Losses associated with unplanned activities – Failure of prime movers and utilities (instrumentation, power, etc.)
B4	Real trips including operator errors	Process upsets. Logistic delays included (e.g. on unmanned facilities).
B5	Post modifications impact	Losses associated with modification work, i.e. adding new pumps / compressors to increase capacity.
B6	Operational Impacts	Flow assurance
C	**Terminal**	**All B items, plus event C1-C3**
C1	Offloading	These are shutdowns caused by (e.g. full storage) offloading equipment failures or tanker not present, bad weather stops loading, etc.
C2	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the battery limit of terminal (third party issues)
C3	Out of product specification (below and above spec)	CO_2, BS and W, etc.
D	**LNG Plants, Gas Plants, etc**	**All B items, plus event D1-D2**
D1	Out of product specification (below and above spec)	CO_2, BS and W, water, etc.
D2	Downstream process shutdowns and restrictions	These are shutdowns caused by downstream process/receiving facilities outside the battery limit of plant (third party issues)
E	**Other**	
E1	Revision shutdowns	Can be considered to be excluded both in predictions and for historical reporting (e.g., when revision shutdowns are defined in sales contracts).
E2	Accidental events	Safety related events. Downtime caused by events which are of catastrophic type, should be reported separately in predictions

Table C.9.4-3 — Downstream events

	Type of event	Comments
A	**Process Unit Unavailability**	Process plants typically consists of a number of process units
A0	Unplanned shutdowns	Losses arising from equipment failures, power, instrumentations, utilities.
A1	Domino losses	Losses caused by shutdown/slowdown of other process units
A2	Turnarounds	Losses associated with planned turnarounds (major overhauls of process units planned well in advance)
A3	Commercial	Losses caused by production constraints due to commercial aspects of the business

Note: In downstream industry a wide range of performance measures are utilized. Examples are given below.

Mechanical Availability

This indicator measures the average time available for processing accounting for turnarounds and non-turnaround maintenance.

Operational Availability

This indicator measures the average time available for processing accounting for turnarounds, non-turnaround maintenance, and regulatory/process downtimes.

On-Stream Availability

This processing indicator accounts for all outages and indicates the average time available for processing including downtime for annualised turnarounds, regulatory/process-related, non-turnaround maintenance, and all other downtimes.

Days Down For Routine Maintenance

This indicator represents the annualised down days scheduled and unscheduled outages for repairs that are not accounted for in the turnaround data.

Annex D
(informative)

Catastrophic events

Some serious, infrequent events may cause long-term shutdown of production. These events are classified as catastrophic, and should be distinguished from the more frequent events which are considered in analyses of production availability and deliverability. The catastrophic events should be treated separately in production assurance analyses.

Typical catastrophic events include

- earthquakes;
- fires and explosions;
- blowouts;
- sabotage;
- structural collapse;
- major problems with casing or wellheads;
- riser or export pipeline ruptures;
- falling loads with large damage potential;
- other events or combinations of events with large damage potential.

Important factors in the analysis of catastrophic events are considered in more detail below.

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 has therefore to be predicted. The uncertainty related to the value of A can be expressed by a probability distribution H(a), with mean or expected value A* being the predictor of A. When performing a Monte-Carlo study of the production availability we generate a sequence of independent, identically distributed quantities, say $A_1, A_2, \ldots, A_n$, from this probability distribution. By using the sample $A_1, A_2, \ldots, A_n$ we can estimate this distribution.

In theory and as far as the uncertainty distribution H(a) is concerned, there is no problem in including catastrophic events into the analysis. If a catastrophic event results in a production loss z and its associated probability equals p, this is to be reflected in the distribution H. But using the «full distribution» would make it difficult to predict A using the expected value. The spread around the mean would be very large, and the form of the probability density could be bimodal far away from the typical Gaussian distribution. The problem is that the expected value contribution from the catastrophic event is normally a rather small quantity, namely $p \cdot z$, which is an unrepresentative contribution to the production loss. If the catastrophic event occurs, the actual loss would be z and this could mean a dramatic reduction in the production availability A.

If the time period considered is long, then the probability that a catastrophic event shall occur could be quite large and consequently the contribution $p \cdot z$ significant. Hence in such cases the inclusion of catastrophic events would be more meaningful.

Criterion for inclusion in analyses:

The consequences for production as a result of catastrophic events in production and transportation systems should always be considered either by production availability analysis or total risk analysis. In general, catastrophic events should not be included in production availability analysis, but in risk and financial analyses. A criterion for exclusion from production availability analyses may be as follows:

- the probability that the event occur during lifetime of the system is less than 25%; and
- the downtime as a result of one occurrence of the event during the lifetime shall result in a reduction of the production availability or deliverability of more than 1%.

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

In analyses limited to subsystems, one shall consider from case to case whether the catastrophic events should be included.

Annex E
(informative)

Handling of uncertainty

The purpose of the reliability and production availability analyses is to predict the performance of the system being analysed. Consider the production availability as an example. Let A be the actual production availability for the installation for the time period considered. This quantity is uncertain (unknown) when the analysis is carried out and it has therefore to be predicted. To structure and reduce this uncertainty we develop a model which describe important phenomena and incorporate relevant experience data. Yet there are uncertainties associated with the value of the production availability, and this uncertainty can be expressed by a probability distribution H(a). This distribution is generated by uncertainties on equipment level, reflected for example by distributions of failure and restoration times, and by a system model linking the various system elements (equipment, storage, delivery points, etc.) together.

When performing a Monte Carlo study of the production availability we generate a sequence of independent, identically distributed quantities, say A1, A2, …, An, from this probability distribution. By using the sample A1, A2,..., An we can estimate this distribution and its mean. Depending on the number of simulations n, the accuracy of this estimation can be more or less good. If the variance of the distribution is large, for example as a result of long downtimes in some simulations, a rather high number of simulations is required to estimate the mean accurately.

The mean (expected value) of the distribution H(a) is normally used as the predictor for the production availability A. The spread of the distribution (and of A1,A2,...,An), for example expressed by the standard deviation, gives valuable information about the confidence the analysis team has to obtain an accurate prediction. If the spread is small, the analysis team is confident that the prediction will be close to the actual value, whereas if the spread is large, the analysis team would expect relatively significant deviations from the predicted value.

The value of A and consequently the uncertainty related to the value of this quantity is affected by

the downtime pattern of equipment and systems;
When will a equipment failure occur and what will be the consequences on the production? Depending on the occurrences of failures and the length of the downtimes, the production availability may vary from one period of time to another.

operating factors such as wind, waves and access to certain repair resources;
Such factors could induce variations from one period of time to another.

the time period considered;
For a given installation the production availability for any given year may, for example, vary between 95 % and 99 %, while production availability for the same installation measured any day, may vary from 0 % to 100 %.

These factors will influence the uncertainty distribution H(a) and its mean value (the predictor) A*. But H and A* will in addition be influenced by the way we express and model system performance. Important aspects are

system definition;
The initial project phases will provide limited access to reliable information on technical solutions, production and sale profiles, operating and maintenance philosophies, logistics conditions etc. The analyses have therefore to be based on a number of assumptions and conditions. As the project progresses, more information will be available and this type of uncertainty can be reduced to a minimum.

models used for total system and its elements;
All models have limitations and weaknesses, and consequently they can lead to more or less good predictions of the actual quantities of interest;

quality of input data for equipment;
Predictions could be poor for example as a result of using generic data which are not representative for the relevant type of equipment, small observation time as a basis for applied data, and the use of data being extracted from operating and environmental conditions which are not representative. Probability distributions are established for equipment failure times and restoration times, using relevant experience data and expert judgements, and reflecting the uncertainties of the actual values of these times.

The purpose of importance and sensitivity analyses is to identify critical contributors to production unavailability (undeliverability) and describe the sensitivity of the input data used and the assumptions made. In an importance and sensitivity analysis the effects of changes in various parameters on the overall results, are studied, and these analyses thus represent a tool for expressing certain aspects of uncertainty. Consider for example an analysis where we study the effect of increasing and decreasing the MTTF of the various type of equipment with x %. Such an analysis will identify how critical the assumed MTTFs are for the results and how sensitive the results are for variations in the MTTFs. So if we allow for consideration of a class of probability distributions corresponding to these MTTFs, reflecting the uncertainties involved in predicting the lifetimes of the equipment, the results show a range of possible values associated with these different models. Note that importance and sensitivity analysis only reflect some aspects of uncertainty. Only one parameter is changed at a time.

Uncertainty is related to information. More information about the system and its performance will reduce uncertainty. It will however be a question about cost-benefit whether it is worthwhile to obtain more information to improve the decision basis. The uncertainties will be reduced in the later project phases, but it will never be completely eliminated.

The following example illustrates how certain types of uncertainty can be handled. Assume that it is not known whether simultaneous production and maintenance (intervention) will be allowed for a subsea installation. The following three alternative methods are possible to deal with this in a production availability analysis:

a) it is assumed that simultaneous production and maintenance will be permitted;

b) it is assumed that simultaneous production and maintenance will be permitted, but an additional sensitivity analysis is carried out in which it is assumed that simultaneous production and maintenance will not be permitted;

c) the uncertainty related to whether simultaneous production and maintenance is being permitted is expressed by a probability, for example 70%. This probability is included in the analysis.

In method a) we allow no uncertainty related to the simultaneous production and maintenance. Hence if this assumption is correct we can obtain accurate predictions, but otherwise, the analysis result could be poor. Method b) goes one step further and calculates the consequences for production also with the alternative assumption. So we have in fact two models. In this case the analysis can be used also as a basis for economic calculations in connection with application for permission for simultaneous production and maintenance.

The method c) is consistent with the approach presented above for dealing with uncertainties, but it has to be used with care. In practice (over a period of time) one will either allow simultaneous production and maintenance, or not, and consequently the predictions could be poor compared to real values. In cases like this, the total distribution of the production availability should be focused, not only the mean value which is not so informative.

To reduce unwanted variability from one analysis to another, as a result of arbitrariness and superficiality in the analysis process, guidelines or standards related to methods and data are required. Such standards could for example be related to the use of a specific probability distribution for the failure time of equipment.

Bibliography

[1] BS 5760, *Reliability of systems, equipment and components, British Standards Institution, London.*

[2] IEC 60050-191, *International Electrotechnical Vocabulary, Chapter 191: Dependability and quality of service.*

[3] IEC 60300-1, *Dependability management - Part 1: Dependability programme management*

[4] IEC 60300-2, *Dependability management - Part 2: Dependability programme elements and tasks.*

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

[6] IEC 60300-3-3, *Dependability management - Part 3: Application guide – Section 3: Life cycle costing.*

[7] IEC 60300-3-4, *Dependability management - Part 3: Application guide - Section 4: Guide to the specification of dependability requirements.*

[8] IEC 61508, *Functional safety of electrical / electronic / programmable electronic safety-related systems – (all parts).*

[8] IEC 61511, *Functional safety - Safety instrumented systems for the process industry sector – (all parts).*

[9] ISO 15663-1, *Petroleum and natural gas industries - Life cycle costing - Part 1: Methodology*

[10] ISO 15663-2, *Petroleum and natural gas industries - Life cycle costing - Part 2: Guidance on application of methodology and calculation methods*

[11] ISO 15663-3, *Petroleum and natural gas industries - Life cycle costing Part 3: Implementation guidelines*