

NORSOK STANDARD

**REGULARITY MANAGEMENT & RELIABILITY
TECHNOLOGY**

Z-016
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FOREWORD

NORSOK (The competitive standing of the Norwegian offshore sector) is the industry's initiative to add value, reduce cost and lead time and eliminate unnecessary activities in offshore field developments and operations.

The NORSOK standards are developed by the Norwegian petroleum industry as a part of the NORSOK initiative and supported by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Engineering Industries). NORSOK standards are administered and issued by NTS (Norwegian Technology Standards Institution).

The purpose of NORSOK standards is to contribute to meet the NORSOK goals, e.g. by replacing individual oil company specifications and other industry guidelines and documents for use in existing and future petroleum industry developments.

The NORSOK standards make extensive references to international standards. Where relevant, the contents of a NORSOK standard will be used to provide input to the international standardisation process. Subject to implementation into international standards, this NORSOK standard will be withdrawn.

Annex A is normative. Annex B,C,D,E and F are informative.

INTRODUCTION

The purpose of this standard is to establish requirements and guidelines for systematic and effective planning, execution and use of reliability technology to achieve cost-effective solutions. It is also an objective of the standard to arrive at a common understanding with respect to use of reliability technology in the various life cycle phases.

1 SCOPE

This NORSOK standard covers analysis of reliability and maintenance of the components, systems and operations associated with exploration drilling, exploitation, processing and transport of petroleum resources. The standard focuses on regularity of oil and gas production and associated activities, but also covers system and equipment reliability and maintenance performance in general.

The standard presents requirements to planning, execution and use of reliability technology, structured around the following main elements:

- Regularity management for optimum economy of the facility through all of its life cycle phases, while also considering 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.

2 NORMATIVE REFERENCES

The following standards include provisions which, through references in this text, constitute provisions of this NORSOK standard. The latest issue of the references shall be used unless otherwise agreed. Other recognised standards may be used provided it can be shown that they meet or exceed the requirements of the standards referred to below.

NORSOK O-001	LCC for systems and equipment
NORSOK O-002	LCC for production facility
NORSOK Z-008	Criticality classification method
ISO 14224	Collection and exchange of reliability and maintenance data for equipment (FDIS)
IEC 60300-3-4	Dependability management - Part 3: application guide - Section 4: Guide to the specification of dependability requirements

3 DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

Active repair time	The part of the downtime during which a repair action is performed on an item, either automatically or manually, excluding logistic delays (e.g. manpower and spares), preparation for repair and preparation for production.
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Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided. This ability is expressed as the proportion of time(s) the item is in the functioning state.
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Note 1: This ability depends on the combined aspects of the

	reliability, the maintainability and the maintenance supportability. <u>Note 2</u> : Required external resources, other than maintenance resources do not affect the availability of the item.
Can	Verbal form used for statements of possibility and capability, whether material, physical or casual.
Common cause failure	Failures of different items resulting from the same direct cause where these failures are not consequences of another.
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.
Deliverability	The 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.
Design life	Planned usage time for the total system. <u>Note</u> : 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.
Downtime	The time interval during which an item is in the down state which is characterised either by a fault, or by a possible inability to perform a required function, e.g. during preventive maintenance.
Failure	Termination of the ability of an item to perform a required function. <u>Note 1</u> : After failure the item has a fault. <u>Note 2</u> : “Failure” is an event, as distinguished from “fault”, which is a state.
Failure mechanism	The physical, chemical or other processes which lead or have led to a failure.
Failure mode	The effect by which a failure is observed on the failed item.
Failure rate	Number of failures relative to the corresponding operational time. <u>Note 1</u> : In some cases time can be replaced by units of use. In most cases $1/\text{MTTF}$ 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. <u>Note 2</u> : Failure rate can be based on operational time or calendar time.
Fault	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.

Idle time	The part of the uptime which an item is not operating.
Maintainability	The 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. <u>Note</u>: The term maintainability is also used as a measure of maintainability performance.
Maintenance supportability	The ability to provide the resources, services and management necessary to carry out maintenance <u>Note</u>: Mobilisation times of resources are used to quantify this ability in a regularity analysis.
May	Verbal form used to indicate a course of action permissible within the limits of the standard.
Mean time between failures	$MTBF=MTTF+MDT$. If the downtime equals the repair time; $MTBF=MTTF+MTTR$.
Mean time to failure	The mean time to failure is a predictor of the time to failure. <u>Note</u>: The MTTF of an item could be longer or shorter than the design life of the system.
Mean time to repair	The mean time to repair is a predictor of the active repair time.
Observation period	The time period during which regularity and reliability data is recorded.
Operating time	The time interval during which the item is performing its required function.
Predictive maintenance	Condition based maintenance carried out following a forecast derived from the analysis and evaluation of significant parameters of the degradation of the item.
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.
Production availability	The ratio of production to planned production, or any other reference level, over a specified period of time. <u>Note 1</u>: 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.

Regularity	A term used to describe how a system is capable of meeting demand for deliveries or performance. Production availability, deliverability or other appropriate measures can be used to express regularity. <u>Note</u>: The use of regularity terms must specify whether it represents a predicted or historic regularity performance.
Regularity analysis	Systematic evaluations and calculations carried out to assess the regularity of a system. <u>Note</u>: 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.
Regularity expenditures	The total cost of lost or deferred production due to downtime.
Regularity management	Activities implemented to achieve and maintain a regularity which is at its optimum in terms of the overall economy and at the same time consistent with applicable framework conditions.
Regularity objectives	An indicative level for the reliability/regularity one wishes to achieve. Objectives are expressed in qualitative or quantitative terms. Objectives are not absolute requirements and may be deviated based on cost or technical constraints.
Regularity programme	A description of the organisation, responsibilities and planned activities in one or several project phases with the aim of contributing to cost-effective regularity management of the project.
Regularity requirements	A required minimum level for the reliability/regularity of a system or in a field development project. Requirements are normally quantitative but may be qualitative.
Reliability	The ability of an item to perform a required function under given conditions for a given time interval.
Reliability data	Reliability data is meant to include data for reliability, maintainability and maintenance supportability.
Shall	Verbal form used to indicate requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted, unless accepted by all involved parties.
Should	Verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required.

Uncertainty	Lack of knowledge about an unknown quantity. The uncertainty is expressed by probabilities.
Uptime	The time interval during which an item is in the up state which is characterised by the fact that it can perform a required function, assuming that the external resources, if required, are provided.
Variability	Variations in performance measures for different time periods under defined framework conditions. <u>Note:</u> 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.

Figure 3.1 illustrates the relationship between some important reliability and regularity terms.
Figure 3.2 illustrates the various contributors to downtime.

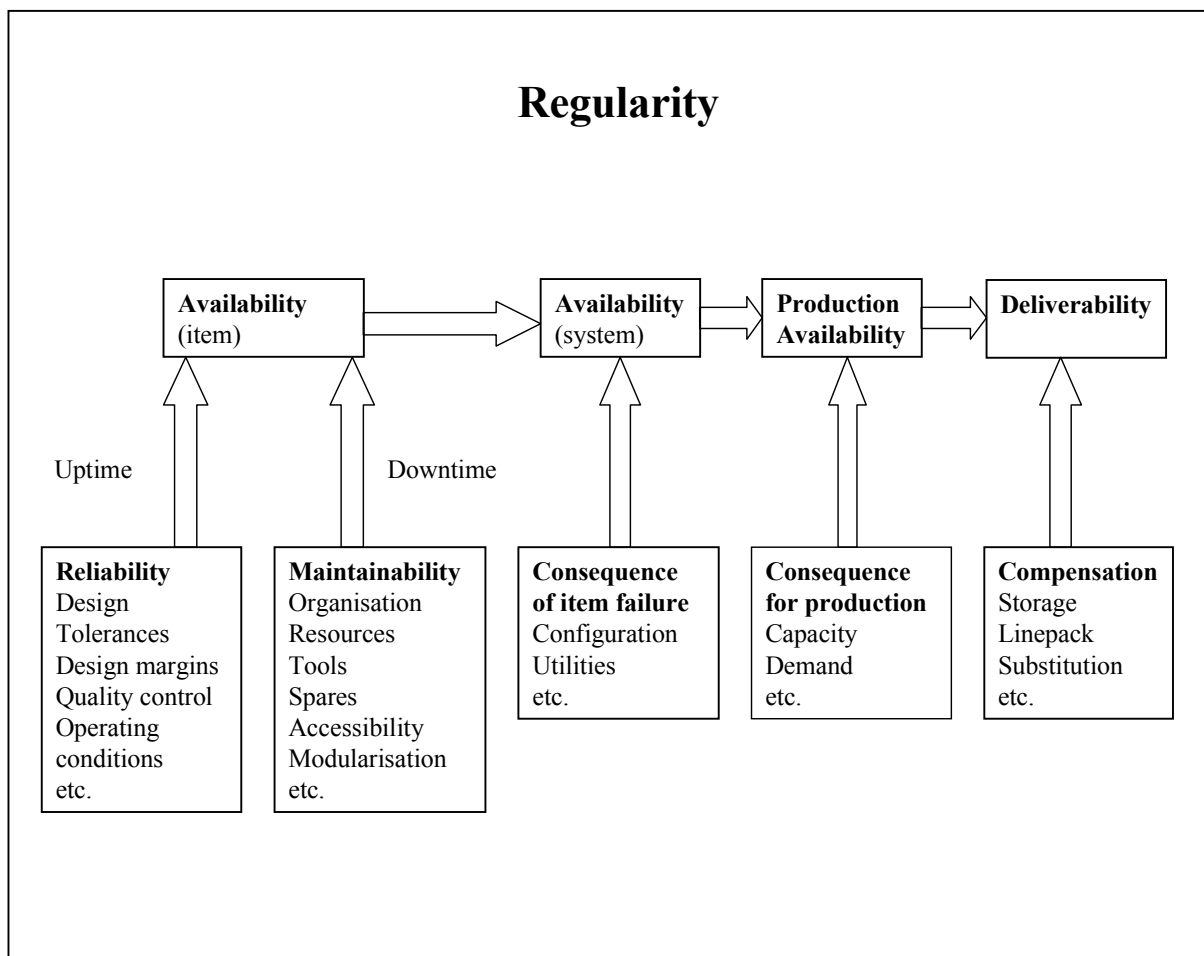


Figure 3.1 - Illustration of relationship between some regularity terms.

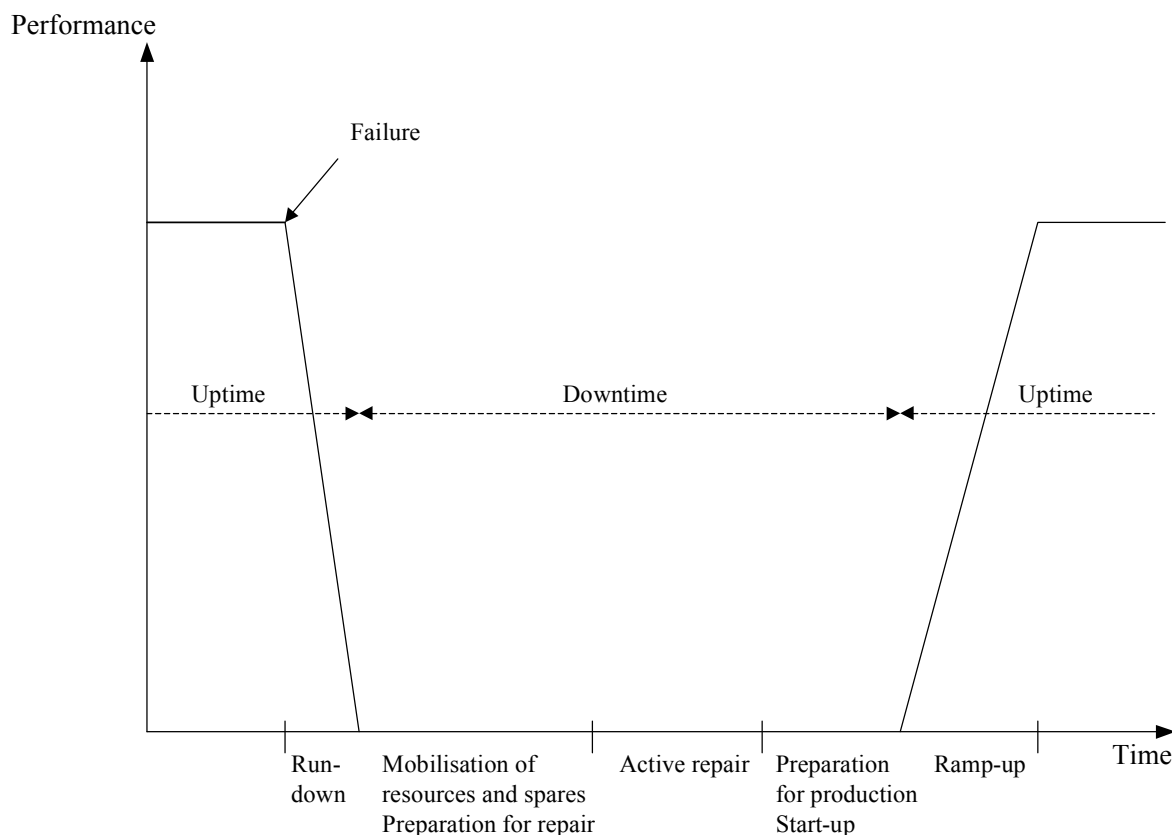


Figure 3.2 - Illustration of downtime associated with a failure event.

3.2 Abbreviations

CAPEX	Capital expenditures
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FTA	Fault Tree Analysis
HSE	Health, Safety and Environment
IEC	International Electro-technical Commission.
ISO	International Organisation for Standardisation.
LCC	Life Cycle Cost
MDT	Mean downtime
MFDT	Mean fractional deadtime
MTBF	Mean time between failures
MTTF	Mean time to failure
MTTR	Mean time to repair
OPEX	Operational expenditures
OREDA	Joint industry project on collection and maintaining reliability data from exploration & production operations
RBD	Reliability Block Diagram
RBI	Risk Based Inspection
RCM	Reliability Centred Maintenance
REGEX	Regularity expenditures

REGOP Regularity and operability review
 RMP Regularity Management Programme

4 REGULARITY MANAGEMENT AND DECISION SUPPORT

4.1 Framework conditions

The objectives associated with systematic regularity management is to contribute to the alignment of design and operational decisions with corporate and business objectives.

In order to fulfil these objectives, technical and operational means as indicated in figure 4.1 may be used during design or operation to change the regularity level. Regularity management must include surveillance of project activities and decisions which may have an undesired effect on regularity.

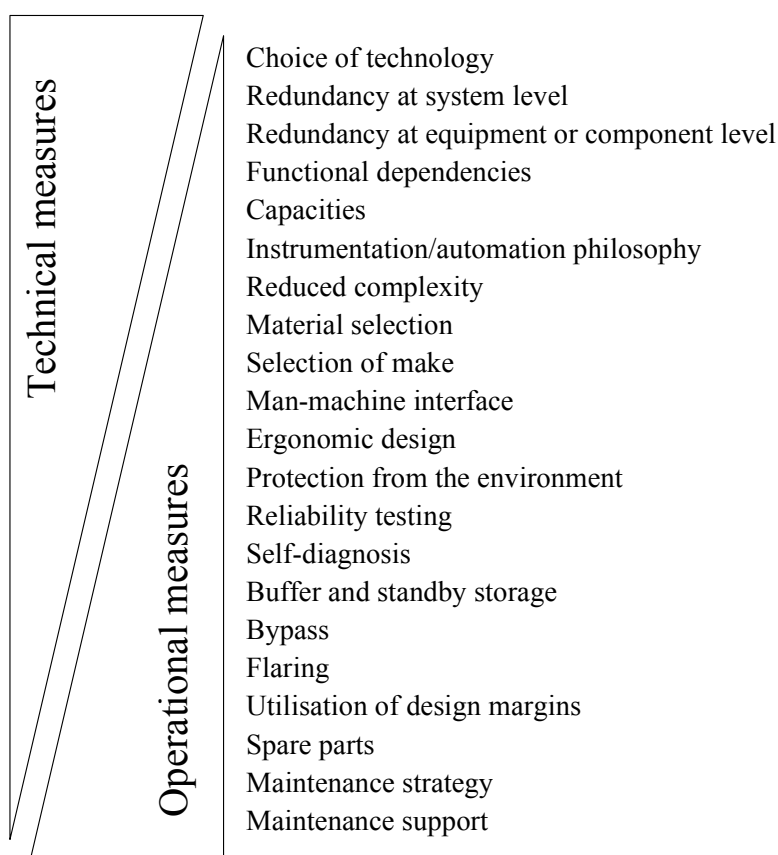


Figure 4.1: Important measures for control of regularity.

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. As an economic criterion minimum life cycle cost should be used. The achievement of high regularity is of limited importance unless the associated costs are considered. This standard should therefore be considered together with the NORSOK standards O-001 "LCC for systems and equipment" and O-002 "LCC for production facility".

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 4.2 below. 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 regularity parameters are predicted and the preferred solution is identified based on a LCC evaluation/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 regularity and reliability function to be addressed by qualified team members.

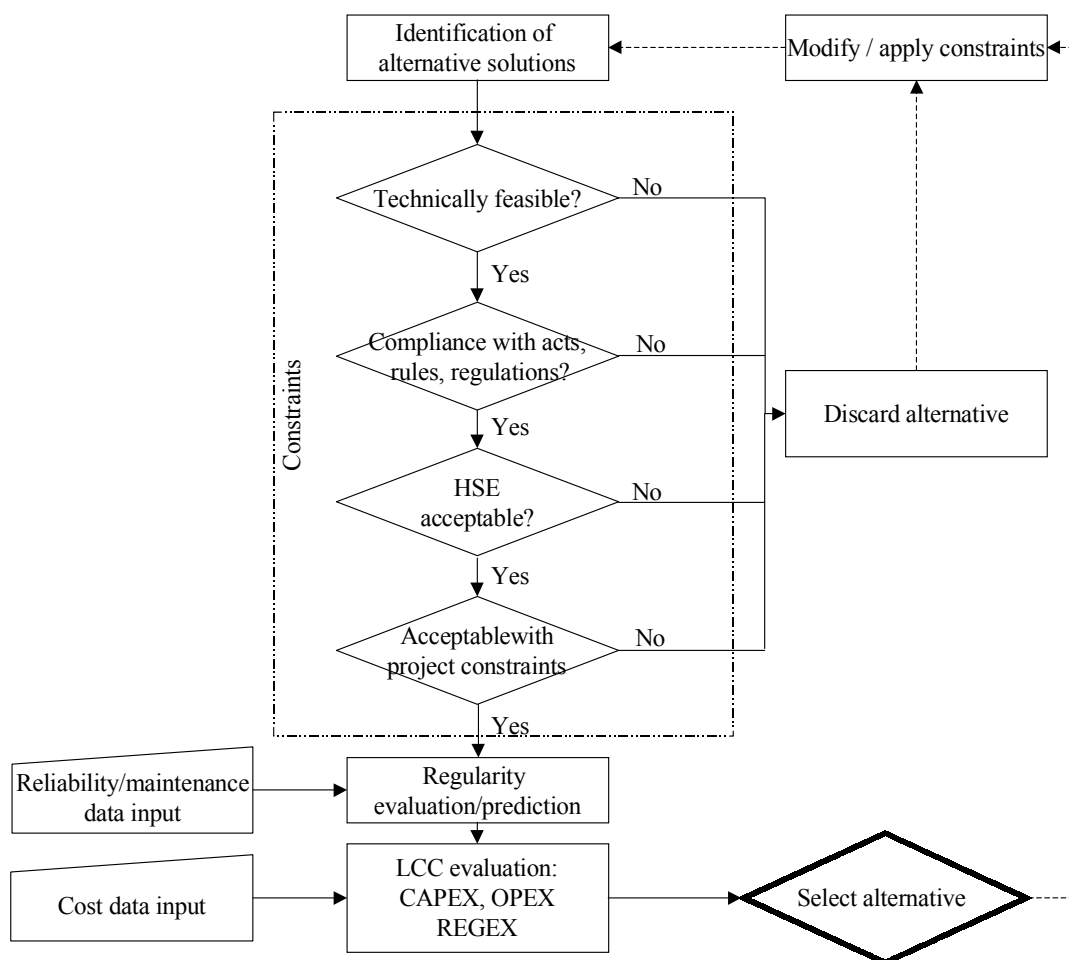


Figure 4.2 - Optimisation process

4.3 Regularity objectives and requirements

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

Regularity objectives and requirements should be used only if they are defined as a consequence of the framework conditions or constraints that apply.

The regularity objectives and requirements can be qualitative or quantitative. They can be formulated with respect to production availability, deliverability, reliability (time to failure of various failure modes), maintainability (mean or maximum duration of the shutdowns, intervention demand), redundancy (acceptable consequences of a failure), etc. Associated battery/boundary limits and important assumptions shall be clearly stated, especially to correctly interpret quantitative requirements.

4.4 Regularity Management Programme

4.4.1 Objectives

A Regularity Management Programme shall serve as a management tool in the process of achieving regularity objectives by cost-effective means and shall be a living document through the various life cycle phases. Regularity Management Programme shall be established for each field development project and updated at major milestones as required as well as being established for existing fields in operation. The Regularity Management Programme shall:

- Ensure systematic planning of regularity/reliability work within the scope of the programme.
- Define optimisation criterion.
- Define regularity objectives and requirements, if any.
- Describe the regularity activities necessary to fulfil the objectives, how they will be carried out, by whom and when. These shall be further outlined in separate regularity or reliability activity plans.
- Ensure that proper consideration is given to interfaces of regularity and reliability with other activities.

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

4.4.2 Programme activities

Regularity 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 regularity 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.

Regularity management shall be a continuous activity throughout all phases. Important tasks of regularity management are to monitor the overall regularity level, manage reliability of critical components and continuous identification of the need for regularity activities. A further objective of regularity management is to contribute with practical technical or operational recommendations.

The emphasis of the regularity activities will change for the various phases. Early identification and prediction of regularity enables the decision-maker to balance regularity aspects against LCC and other relevant aspects. Decisions made early in project development have a much greater influence on regularity as well as LCC than those made later. Early activities should therefore focus on optimisation of the overall configuration while attention to detail will increase in later phases. From the detail design phase into operations, increased attention to maintainability aspects is required. Certain key events will determine the prior need for particular activities. These activities can be effective only if reported in a timely manner.

A criticality classification based on NORSOK standard Z-008 *Criticality classification method* will assist in identifying regularity critical systems that should be subject to more detailed analysis and follow-up.

An overview of regularity activities in the various life cycle phases are given in the table below, while more detailed requirements are given in clause 4.5. The life cycle phases are typical for a field development. Some of the phases may overlap. If the phases in a specific project differ from those below, the activities should be defined and applied as appropriate.

Activity	Life cycle phase								
	Feasibility study	Conceptual design	Engineering	Procurement	Fabrication/ construction	Commissioning	Preparation for operation	Operation	Modification
Regularity management	***	***	***	***	***	***	***	***	***
Regularity analyses	**	***	***	*	-	-	*	*	**
Reliability/availability/LCC evaluation of systems critical to production, safety, environment or other operations	**	**	***	*	*	-	**	*	**
Maintenance and operational planning	-	*	**	**	-	-	***	**	*
Design reviews	*	**	**	*	-	-	-	-	**
Reliability/qualification testing of selected items	-	*	*	*	*	*	*	-	-
Data collection and analysis	-	*	*	-	-	*	*	***	-

Table 4.1 Overview of regularity activities in life cycle phases.

- *** Shall be performed
- ** Should be performed
- * May be performed
- Not applicable

4.5 Regularity activities in life cycle phases

4.5.1 General

The following clauses give requirements to the activities that shall or should be carried out in the various life cycle phases of a typical field development.

The selection of activities to be carried out shall be based on a judgement of their potential to add value to the project/installation or whether they are required for other reasons.

Other projects than field 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.

4.5.2 Feasibility study

The objective in the feasibility study is to find a technically and economically feasible development option.

The following activities shall be performed in the feasibility phase:

- Regularity management including:
- Establishment and implementation of the regularity management programme.
- Clarification of the framework conditions of the project.
- Clarification of the need for analyses of main alternatives to be performed.

The following activities should be considered in the feasibility phase:

- Identification of critical systems.
- A coarse regularity analysis including prediction of appropriate performance measures.
- Provide regularity input to LCC.
- Assessment of the risk of using new technology.
- Identification of equipment with scarce reliability data and initiation of data collection from installations in operation.

4.5.3 Conceptual design

In the conceptual design phase the objective is to establish the final development concept with design basis and functional requirements. Further the operation and maintenance philosophy will be outlined.

The following regularity activities shall be performed:

- Update the regularity management programme.
- Update or perform regularity analysis and predictions.
- Develop and update lists of regularity-critical systems, equipment and assumptions regarding operation.
- Provide regularity input to LCC evaluations of alternatives as required.

The following activities should be considered:

- Initiate programmes for reliability improvement of critical equipment.
- FME(C)A, especially of systems utilising new technology
- Detail regularity objectives and requirements, framework conditions and conditions for critical equipment and for the entire system, and incorporate regularity objectives and requirements in technical specifications and other basic contract documents as required.
- Identify need for reliability data collection for special equipment.
- Regularity design reviews.
- Input to definition of manning level.
- Input to operation strategies.
- Input to maintenance planning.

4.5.4 Engineering and Procurement

The following activities shall be performed in the engineering and procurement phases:

- Update the regularity management programme for the phase.
- Update regularity analysis and predictions as required to serve as a tool to monitor regularity and provide input to the decision making process.
- Develop and update lists of regularity-critical systems, equipment and assumptions regarding operation.
- Perform detailed reliability analyses of selected systems as required.
- Perform reliability/availability evaluations of safety systems, input to risk analysis.
- Provide regularity input to LCC evaluations of design alternatives or as a tool in procurement
- Incorporate regularity objectives and requirements in relevant requisitions.
- Evaluate proposed design changes with respect to regularity impact.

The following activities should be considered:

- Contribute to establishment of maintenance programme.
- Participate in design reviews to verify maintainability aspects.
- Reliability based spare parts optimisation.
- Reliability testing of selected items.

4.5.5 Fabrication, Construction and Commissioning

Regularity management shall be performed with a main objective to evaluate the regularity impact of proposed changes.

In the fabrication and installation phase reliability testing of selected items may be performed. Screening and burn-in of selected components may be performed.

4.5.6 Preparation for operation

Preparation for operation will be activities which will be run in parallel to other phases. The following activities shall be performed:

- Prepare maintenance programme utilising reliability and regularity knowledge
- Prepare spare parts programme
- Prepare plans and systems for regularity and reliability data collection.

4.5.7 Operation

Reliability, maintainability and maintenance supportability data shall be systematically collected for future use in reliability and regularity prediction. Reference is made to ISO 14224 “Collection and exchange of reliability and maintenance data for equipment”.

Recording and reporting of achieved regularity/production availability/deliverability or other relevant regularity performance measures shall be performed.

Collected regularity and reliability data should be analysed for trends and problems that may require corrective action. A programme of post-design improvements should be considered whenever poor reliability results in unacceptable production shortfalls, maintenance costs or risk to personnel.

The experience from the operational phase of the project shall be transferred to parties involved in the design phase in order to stimulate improvements in design of new equipment and installations. This includes a review of assumptions made to the predictions in the design phase in comparison to actual conditions experienced during operation including operational principles and maintenance logistics.

Reliability and availability aspects should be considered for corrective maintenance planning.

Furthermore, regularity and reliability assessment can be needed for operation and production optimisation in the operational phase.

4.5.8 Modification

Extensive modifications shall be analysed for their potential impact on regularity. Modifications implying tie-in of other fields or increased production rate can cause lower regularity of the facilities as the degree of redundancy is reduced.

Major modifications may be considered as a project with phases similar to those of a field development project. The requirements to regularity activities as given in the above clauses will apply.

5 REGULARITY ANALYSES

5.1 General requirements

Regularity analyses shall be planned, executed, used and updated in a controlled and organised manner according to plans outlined in the regularity management programme.

Regularity 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 must be performed at a point in time when sufficient details are available to provide sustainable results. However, results must be presented in time for input to the decision process.

Regularity 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 regularity analyses of complete installations, but will also apply to reliability and availability analyses of components/systems with obvious modifications.

5.2 Planning

5.2.1 Objectives

The objectives of the analyses shall be clearly stated prior to any analysis. Preferably objectives can be stated in a regularity activity plan as a part of the regularity management programme structure. Objectives can be to:

- Identify operational conditions or equipment units critical to regularity
- Predict production availability, deliverability, availability, reliability, etc.
- Compare alternatives with respect to different regularity aspects
- Identify technical and operational measures for regularity 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 regularity objectives or requirements

5.2.2 Organisation of work

A working group shall be set up for conducting the analysis. This group must have knowledge of methods used in regularity 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 regularity analysis is a multi-disciplinary activity, close co-operation with other relevant disciplines is mandatory.

5.2.3 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 must be selected which will provide the desired basis for decision-making. It shall also be decided whether to include the regularity 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.

5.3 Execution

5.3.1 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.

5.3.2 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 regularity 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 chapter 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 clause 6.2 of this standard.

5.3.3 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

5.3.4 Analysis and assessment

5.3.4.1 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 regularity 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 0 (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 clause 5.3.7.

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

5.3.4.2 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.

5.3.4.3 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 regularity and reliability improvement.

For conventional reliability analysis methods such as fault tree analysis, 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 or undeliverability 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.

5.3.5 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 regularity management system shall be used to follow-up and decide upon recommendations. Recommendations may concern design issues or further regularity analyses/assessments. In the latter case the interaction with the regularity management programme 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.

5.3.6 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 regularity analysis report in order to show all regularity loss contributors.

Additional guidance is given in Annex E.

5.3.7 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 F.

6 RELIABILITY AND REGULARITY DATA

6.1 Collection of reliability data

6.1.1 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

6.1.2 Equipment boundary and hierarchy definition

Clear boundary description is imperative, and a strict hierarchy system must be applied. Boundaries and equipment hierarchy shall be defined according to ISO 14 224 – Collection and exchange of reliability and maintenance data for equipment. 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

6.1.3 Data analysis

To predict the time to failure (or repair) of an item, a probability model must 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.

6.2 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 1st 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.

6.3 Regularity data

Regularity performance at facility/installation level shall be reported in a way that enables systematic regularity management to be carried out. The type of installation and operation will determine the format and structure of regularity reporting. Annex C outlines type of events to be covered for a production facility. Relationship between facility regularity performance data and

critical equipment reliability data is needed. Assessment of actual regularity 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 regularity loss and areas for improvement can be identified. In this context, reliability techniques can be used for decision-support and calibration of regularity predictions. Comparisons to earlier regularity predictions should be done, thereby gaining experience and provide feedback to future and/or other similar regularity predictions.

7 REGULARITY OBJECTIVES AND REQUIREMENTS IN CONTRACTS

7.1 General

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

IEC 60300-3-4 - Dependability management - Part 3: application guide - Section 4: Guide to the specification of dependability requirements, should be considered.

7.2 Specifying regularity

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

- Limitations and boundaries
- Application of the system
- Definition of a fault
- Operating conditions
- Environmental conditions
- Maintenance conditions
- Methods intended to be applied for the verification of compliance with the regularity requirements (see clause 7.3)
- 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
- 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)
- Regularity activities to be performed

7.3 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.

7.4 Co-operation between operator and supplier

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

8 INTERFACES

8.1 General

Several functions and systems will affect regularity, and there will be a large number of interfaces. Some interfaces are discussed below.

8.2 Life Cycle Cost

Regularity predictions is an important input parameter to life cycle cost 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 regularity expenditures (REGEX) as part of the regularity analysis, whilst CAPEX and OPEX is 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 regularity analysis outlined in this standard.

Each alternative shall be presented with the appropriate regularity performance measures as a percentage of planned production. If regularity 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 REGEX 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 regularity input may be limited to the differences between the alternatives. The regularity input shall include relevant figures for oil production, gas export and other as required.

8.3 Safety and environment

8.3.1 General

The main principle of optimisation of design or selection between alternative solutions is economic optimisation within given constraints and framework conditions. An important category of such constraints and conditions are given by the requirements to health, safety and environment. It is important for management decision-making to have a systematic and thorough approach to critical issues where a proper balance between safety, environmental and economic (regularity) constraints is needed. Thereby, both high safety and optimum regularity can be achieved successfully.

8.3.2 Risk and emergency preparedness analysis

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

- Input to the risk and emergency preparedness analysis in terms of reliability of safety systems (fire water system, fire & gas detection system, ESD system). Such individual system analyses may be a part of the overall regularity 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 regularity.
- Production unavailability due to catastrophic events (see clause 5.3.6 and annex E).
- As the regularity 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 regularity analyses is recommended.

Reference is made to NORSOK standard Z-013 Risk and emergency preparedness analysis.

8.3.3 Environment

Environmental requirements may have implications on the design and associated operation and maintenance strategies. These may affect regularity, and interfaces and interactions should be focused on. Examples are:

- Flaring restrictions are imposed to reduce environmental impact, and these restrictions could significantly affect production and regularity
- Shutdown operations may differ in the use of chemicals and its effect on downtime duration
- Driver selection for rotating equipment, and source of power
- Poor reliability of safety equipment could have consequences with respect to environmental impact

8.4 Maintenance planning

8.4.1 Maintenance strategy

The maintenance strategy should be established based on the equipment criticality with respect to safety, production loss or maintenance cost. Regularity aspects represent important input to the maintenance planning process. Applications of special interest are RCM analysis, spare parts planning, reliability based testing and risk based inspection.

Compliance with reliability data collection requirements (ISO 14224) is instrumental for the predictive maintenance, e.g. when using equipment reliability performance data to adjust maintenance programme.

8.4.2 Reliability centred maintenance

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 must 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.

The criticality analysis should be based on NORSOK standard Z-CR-008 Criticality Classification Method.

Valid regularity 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 must be ensured. Similarly, the 'living' RCM study information should be consulted when regularity and reliability analyses are updated during operational stages.

8.4.3 Spare parts

The issue of spare parts requires attention in connection with regularity, availability and maintenance analyses etc. at different life cycle stages. Regularity analysis in early phases can reflect critical items requiring spare parts attention and special requirements, and form input to spare parts planning (e.g. long lead items). Similarly, during preparation for operation and in operational phase, spare parts plans and strategies may be input to more precise regularity predictions. Monitoring of equipment reliability and availability performance during operation can require optimisation of spare parts programme, in which also reliability techniques are used.

The establishment of operational spares (for potential usage during first 12 months) and capital spares (long lead items) when preparing for operation requires attention to dominant equipment failure modes and expected frequency and consumption rates, in which reliability engineering and LCC approach is used.

The level of analysis detail for spare parts may differ from case to case for the operating site(s) under consideration, but as a general rule the probability of being in the following states, as well as the corresponding influence on the downtime, should be analysed

- Spare parts stored at operating site (e.g. offshore platform, onshore terminal)
- Operating site store does not exist or is empty, spare parts available at onshore store(s) with associated lead time(s)
- All stores empty, spare parts available at vendors shop only

Examples of analysis result parameters or performance measures are:

- The percentage of time for which the stock level is greater than zero
- The number of repairs delayed by spare part unavailability
- Probability of shortage of spares (Sometimes referred to as risk of shortage)

8.4.4 Reliability/risk based testing

For dormant systems testing intervals can be established on the basis of reliability/risk methodology.

From the safety acceptance criteria or the risk and emergency preparedness analysis there may be requirements to on-demand availability for safety systems. Such systems shall be tested at regular intervals and the test results recorded. The results shall be compared with the reliability requirements to see whether the requirements are met. Based on the results, the test intervals can be adjusted to achieve the required on-demand availability at minimum cost.

8.4.5 Risk based inspection

Risk based inspection is a methodology which aims at establishing an inspection programme based on the aspects of probability and consequence of a failure. The methodology combines regularity 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, regularity, 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 regularity analysis of design alternatives in the planning stages as well as in early maintenance planning.

ANNEX A CONTENTS OF REGULARITY MANAGEMENT PROGRAMME (NORMATIVE)

A regularity management programme should cover the topics given by the following standard table of contents:

Title:

Regularity Management Programme 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 RMP is distributed to parties defined.

2. Regularity philosophy and objectives

2.1 Description of overall optimisation criteria

2.2 Definition of regularity objectives and requirements

Note: Relevant reference to regularity objectives and requirements in contract documents

2.3 Definition of performance measures

3. Organisation and responsibilities

3.1 Description of organisation and responsibilities

Note: Focussing on regularity and LCC, internal and external communication, responsibilities given to managers and key personnel, functions, disciplines, sub-projects, contractors, suppliers. Installation regularity and LCC co-ordination role, e.g. responsible for updating the RMP.

3.2 Regularity QA and Audit functions

4. Activity schedule

4.1 Activity/Life cycle phase - main overview

Note: A table similar to table 4.1 can be included to indicate past and future regularity, reliability and LCC activities.

4.2 Regularity/reliability activities

Note: Regularity 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 regularity or reliability activity plans may exist as stand-alone documents which can be quoted.

5. References

ANNEX B INFORMATIVE REFERENCES

BS 5760 Reliability of systems, equipment and components, British Standards Institution, London

Part 0: Introductory guide to reliability, 1986

Part 2: Guide to the assessment of reliability, 1994

Part12: Guide to the presentation of reliability, maintainability and availability predictions, 1993

prEN 13306 Maintenance terminology, 1998-06-17

ISO: Petroleum and natural gas industries - Collection and exchange of reliability and maintenance data for equipment, ISO/FDIS 14224, draft

Kvalitetsledelse og kvalitetssikringsstandarder, Del 4: Retningslinjer for styring av program for driftspålitelighet, NS-ISO 9000-4 ((IEC300-1) Dependability management - Part 1: Dependability programme management)

IEC 300-2 (1995-12) Dependability management - Part 2: Dependability programme elements and tasks

IEC 300-3-2 (1993-10) Dependability management - Part 3: Application guide – Section 2: Collection of dependability data from the field

IEC 330-3-3 (1996-09) Dependability management - Part 3: Application guide – Section 3: Life cycle costing

IEC 61508 Functional safety: Safety related systems

IEC 50 (191) International Electrotechnical Vocabulary, Dependability and quality of service

NORSOK D-001 Drilling facilities

NORSOK D-010 Drilling and well operations

NORSOK P-001 Process design

NORSOK P-100 Process systems

NORSOK R-001 Mechanical equipment

NORSOK R-100 Mechanical equipment selection

NORSOK U-001 Subsea production systems

NORSOK U-007 Subsea intervention

NORSOK Z-013 Risk and emergency preparedness analysis

ANNEX C OUTLINE OF TECHNIQUES (INFORMATIVE)

C.1 General

Regularity and availability analyses are systematic evaluations and calculations which are carried out to assess the regularity 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. Regularity analyses are part of regularity management. The term “regularity analysis” should be used for analysis of a total facility (e.g. offshore production system). The following can be used as a guide:

- Regularity analysis of installation(s), or operations
- Availability analysis of important systems
- Reliability & availability analysis of equipment/component

Some relevant analysis methods and techniques are described briefly below. Reference is made to reliability analysis textbooks or BS 5760 Part 2 for more detailed descriptions.

C.2 FMEA - Failure modes and effects analysis

A failure modes and effects analysis (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 failure modes, effects and criticality analysis (FMECA).

FMEA and FMECA show the effects of potential failure modes within a system or subassembly, subsystem and system functioning taking into account the possible degradation of the performance and the consequences for safety.

FME(C)A is suitable both as a design tool and as a verification of reliability in the development of a product. It may prove valuable to have the supplier conducting an FME(C)A in connection with system development or purchasing of equipment. This will serve as the supplier's own verification of the equipment, and as a basis for other specified safety and reliability activities. FME(C)As are expensive and time consuming and should therefore only be carried out for novel designs. However, a library of FME(C)A's may be useful as a starting point to minimise study cost.

It should be recognised that FME(C)A is not focusing on downtime, common cause failures or combination of failures.

Although not always formalised, FME(C)A is used as a basis for most regularity predictions and is also used in connection with RCM analyses.

C.3 FTA – Fault tree analysis

Fault tree analysis (FTA) is a means of analysing system failures in terms of combinations of subsystem and lower level faults, and eventually component faults. Because the FTA is a top-down approach it is possible to start the analysis at a very early stage and to complete it as the detailed design is carried out.

The FTA can be carried out as a qualitative or quantitative analysis. The FTA will produce a list of possible serious component fault combinations, including any single point failures. The probability of the top event and hence system reliability or availability can be assessed.

The output from a FME(C)A can be used as input for the FTA. Whereas the FME(C)A is well suited for a system with little or no redundancy, systems with complex redundancies can be analysed with FTA.

A typical application of FTA is analysis of subsystems such as a safety system, a utility system or a part of the main process.

C.4 RBD - Reliability block diagram

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 parameters. Individual units are represented by blocks that are considered to exist in one of only two possible states, operating or failed. The reliability block diagram can be used to carry out system reliability or steady state availability calculations.

The application of RBD will be the same as for 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. This as RBD only covers binary state systems, in contrast to flow network theory which covers multi-state systems. The latter can be treated by simulations (see below).

C.5 Regularity 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 regularity 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.

C.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 shall be performed by a group of persons from relevant disciplines. The design review shall 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

C.7 HAZOP - Hazard and operability study

The purpose of HAZOP studies is to identify hazards in process plants and to identify operational problems and provide essential input to process design. Useful from a regularity point of view; 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.

C.8 REGOP - Regularity and operability review

REGOP 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 must be seen in conjunction with reliability data qualification and suggested estimates which can be assessed in a REGOP exercise
- Evaluate preliminary reliability data for a regularity 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: Mechanical post-work, start-up

A REGOP group is established consisting of regularity analysts and disciplines like process operation and maintenance. During REGOP 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.

C.9 Reliability testing

Several types of reliability testing can be performed in order to ensure a defined reliability of components. In accordance with *BS5760 part2*, 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

Reliability testing is normally applicable for development of components which is to be produced in some number. Reliability testing often implies that components are tested until failure. Reliability testing can be used in connection with equipment qualification programs.

C.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.

C.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 have to be measured.

Note that software systems are special in the manner faults occur:

1. The faults are latent within the software from the start and are hidden.
2. All software which is identical have the same faults.
3. Once a fault is detected and successfully repaired, it will not occur again.
4. Extensive testing will eliminate many software faults.
5. Software must be developed, designed, tested and used with the same kind of hardware. I.e., change of hardware may activate latent faults within the software.

C.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.

C.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; the choice of the most appropriate distribution usually requires prior knowledge of the failure regime that is expected to apply.

C.14 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.

C.15 Spare parts optimisation

The downtimes used in a regularity analysis are dependent on the availability and lead time of spare parts. Spare part optimisation is a part of Integrated Logistic Support (ILS) and will cover issues typically giving answers to questions like:

- Shall spare parts be stored offshore, at an onshore storage or by the vendor?
- How many spare parts of each type should the storage carry?

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.

C.16 Methods of structural reliability analysis

The methods of Structural Reliability Analysis (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 is used to calculate the probability p , 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 reliability block diagram 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 subevents is often not necessary to the same extent as in for example fault tree analysis.

ANNEX D REGULARITY PERFORMANCE MEASURES (INFORMATIVE)

Regularity 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 regularity 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.

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

	Type of event	Comments
A	Wells (downhole and subsea/surface)	
A1	Downhole equipment failure	Regularity impact until well intervention starts
A2	Unplanned downhole well intervention (workover)	Regularity impact arising from repair of downhole failure. Including heavy lifts. Reliability based contingency preparedness is anticipated
A3	Downhole equipment testing	
A4	Planned well activities (drilling, completion, logging)	Regularity impact including heavy lifts which depends on simultaneous activity procedures.
A5	Well production testing	The production loss caused by the need to undertake such testing. The regularity impact depends on test design and procedures.
A6	Well stimulation	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.
B	Subsea	
B1	Subsea equipment failure	Regularity impact until subsea intervention starts
B2	Unplanned subsea intervention	Regularity impact arising from repair of subsea failure, and may include downhole intervention. Reliability based contingency preparedness is anticipated
B3	Subsea equipment testing	
C	Topside (process & utility)	
C1	Equipment failure and repair	Regularity 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	Process upsets. Logistic delays included (e.g. on unmanned platform)
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	These are shutdowns caused by downstream process/receiving facilities outside the battery limits
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	Modifications	Modifications which have impact on regularity and availability
E3	Bad weather	Trips and offloading events may be caused by bad weather.
E4	Accidental events	Safety related events. Downtime caused by events which are of catastrophic type should be reported separately in predictions, see discussion in clause 5.3.6
E5	Labour conflicts	Not to be included in predictions

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

$$\text{Production availability} = \text{Produced volume (Sm}^3\text{)} / \text{Reference level (Sm}^3\text{)}$$

The reference level needs to be defined if these measures shall be predicted or reported. Ideally, the same reference level as used in regularity analyses shall be used also when reporting historical regularity 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 regularity 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 (hrs) / Observation period (hrs)

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.

ANNEX E CATASTROPHIC EVENTS (INFORMATIVE)

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.

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 regularity 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 must therefore 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 $A_1, A_2, \dots, A_n$, from this probability distribution. By using the sample $A_1, A_2, \dots, A_n$ 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 regularity analysis or total risk analysis. In general, catastrophic events should not be included in regularity analysis, but in risk and financial analyses. A criterion for exclusion from regularity analyses may be:

- 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 must result in a reduction of the production availability or deliverability of more than 1%

It should however be considered to refer to the predicted regularity 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 regularity predictions in the regularity analysis.

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

ANNEX F HANDLING OF UNCERTAINTY (INFORMATIVE)

The purpose of the reliability and regularity 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 must therefore 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 $A_1, A_2, \dots, A_n$, from this probability distribution. By using the sample $A_1, A_2, \dots, A_n$ 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 $A_1, A_2, \dots, A_n$), 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 must therefore 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 mean time to failure (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. Three alternative methods are possible to deal with this in a regularity analysis:

- 1) It is assumed that simultaneous production and maintenance will be permitted.
- 2) 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.
- 3) 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 1) 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 2) 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 3) 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.