

Risk based maintenance and consequence classification

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Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, NORSOK standards are, as far as possible, intended to replace oil company specifications and serve as references in the authorities' regulations.

The NORSOK standards are normally based on recognised international standards, adding the provisions deemed necessary to fill the broad needs of the Norwegian petroleum industry. Where relevant, NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of international standards, the relevant NORSOK standard will be withdrawn.

The NORSOK standards are developed according to the consensus principle generally applicable for most standards work and according to established procedures defined in NORSOK A-001.

The NORSOK standards are prepared and published with support by The Norwegian Oil Industry Association (OLF), The Federation of Norwegian Industry, Norwegian Shipowners' Association and The Petroleum Safety Authority Norway (PSA).

NORSOK standards are administered and published by Standards Norway.

Introduction

The purpose of this NORSOK standard is to provide requirements and guidelines for

- establishment of technical hierarchy,
- consequence classification of equipment,
- how to use consequence classification in maintenance management,
- how to use risk analysis to establish and update PM programmes,
- how to aid decisions related to maintenance using the underlying risk analysis,
- spare part evaluations.

This NORSOK standard is applicable for different purposes and phases such as:

- **design phase:** establish initial maintenance programme as an input to manning requirements and system configuration. Selection of capital spare parts;
- **preparation for operation:** development of initial maintenance programmes for implementation into maintenance management systems and selection of spare parts;
- **operational phase:** updating and optimisation of existing maintenance programmes. Guidance for prioritising work orders. Lifetime extension.

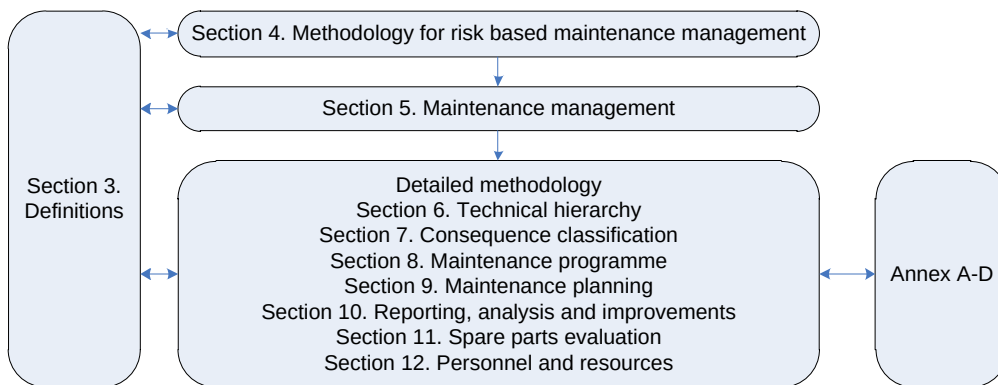
As a basis for preparation and optimisation of maintenance programmes for new and in service facilities all risk elements shall be taken into account, i.e. risks related to

- personnel,
- environment,
- production loss,
- direct and indirect cost including reputation.

The term "criticality analysis" is removed from Edition 2 of this NORSOK standard and replaced with consequence classification. This is due to a conflicting use of criticality analysis in the industry; some use it to describe a consequence analysis and some to describe a risk (probability and consequence) analysis.

This NORSOK standard is meant to define level of how this shall be done and deviations shall only provide better solutions with regards to maintenance management. This NORSOK standard should also be seen in conjunction with ISO 20815.

The standard describes the key work processes with explanation and requirements to each of them, and is organized in the following way:



1 Scope

This NORSOK standard is applicable for preparation and optimisation of maintenance activities for plant systems and equipment including

- offshore topside systems,
- sub-sea production systems,
- oil and gas terminals.

The systems involving the following types of equipment:

- mechanical equipment:
 - static and rotating equipment;
 - piping.
- instrumentation;
- electrical equipment.

Excluded from the scope of this NORSOK standard are

- load bearing structures,
- floating structures,
- risers and pipelines.

In principle, all types of failure modes and failure mechanisms are covered by this NORSOK standard.

This NORSOK standard covers

- definition of relevant nomenclature,
- brief description of main work flow related to maintenance and which elements this typically involves,
- definition of risk model and failure consequence classes,
- guidelines for consequence classification, including
 - functional breakdown of plants and plant systems in MFs and sub functions,
 - identification of MF and sub function redundancy,
 - assessment of the consequences of loss of MFs and sub functions,
 - assignment of equipment to sub functions and associated consequence classes.
- description of how to establish an initial maintenance programme, and how to update an existing programme,
- description on how to use the classification in combination with probability for decision making related to prioritising work orders and handling spare parts.

2 Normative and informative references

The following standards include provisions and guidelines which, through reference in this text, constitute provisions and guidelines of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet the requirements of the referenced standards.

2.1 Normative references

API RP 580,	Risk-Based Inspection
DNV RP-F-206,	Riser Integrity Management
DNV RP-F-116,	Integrity Management of Submarine Pipeline System
DNV RP-G-101,	Risk Based Inspection of Topside Static Mechanical Equipment
IEC 60300-3-11,	Dependability Management Part 3-11: Application guide – Reliability centred maintenance
IEC 61508,	Functional safety for electrical/electronic/programmable electronic safety-related systems
IEC 61511,	Functional Safety – Safety instrumented systems for the process industry sector
ISO 17776,	Petroleum and natural gas industries – Offshore production installations – Guidelines on tools and techniques for hazard identification and risk assessment

ISO 20815 ¹ ,	Petroleum, petrochemical and natural gas industries – Production assurance and reliability management
ISO 13702,	Petroleum and natural gas industries – Control and mitigation of fires and explosions on offshore production installations – Requirements and guidelines
ISO 14224,	Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment
NORSOK S-001,	Technical safety
NORSOK Z-013,	Risk and emergency preparedness analysis
OLF 070,	Guidelines for the Application of IEC 61508 and IEC 61511 in the petroleum activities on the continental shelf
OLF 122,	Life extension guideline

2.2 Informative references

BS 3811,	Glossary of terms used in terotechnology
EN ISO 12100,	Safety of machinery – General principles for design – Risk assessment and risk reduction
EN 13306,	Maintenance – Maintenance terminology
EN 15341,	Maintenance – Maintenance Key Indicators
NORSOK Z-DP-002,	Coding system

3 Terms, definitions and abbreviations

For the purposes of this NORSOK standard, the following terms, definitions and abbreviations apply.

3.1 Terms and definitions

3.1.1

availability

ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided (see EN 13306)

3.1.2

can

verbal form used for statements of possibility and capability, whether material, physical or casual

3.1.3

condition monitoring

continuous or periodic measurement and interpretation of data to indicate the degraded condition (potential failure) of an item and the need for maintenance (see BS 3811)

NOTE Condition monitoring is normally carried out with the item in operation, in an operating state or removed, but not subject to dismantling.

3.1.4

consequence

outcome from an event

NOTE There may be one or more consequences from an event. Consequences may range from positive to negative. However, consequences are always negative for safety aspects. Consequences may be expressed qualitatively or quantitatively (see API RP 580).

3.1.5

consequence classification

quantitative analysis of events and failures and assignment of the consequences of these.

NOTE See definitions in 3.1.6, 3.1.7 and 3.1.8.

¹ NORSOK Z-016 was replaced by ISO 20815 in 2008.

3.1.6**consequence HSE**

health, safety and/or environmental consequence of an event

3.1.7**consequence production**

effect with regard to production of a functional failure where effects of mitigation (e.g. spares, manning, tools) and compensation measures are not considered (= unmitigated consequence)

3.1.8**consequence other**

other consequences as a result of a functional failure other than HSE or production consequence

NOTE May also include monetary losses and loss of reputation.

3.1.9**corrective maintenance**

maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function (see EN 13306)

3.1.10**equipment class**

class of similar type of equipment units (see ISO 14224)

NOTE E.g. all pumps.

3.1.11**failure**

termination of the ability of an item to perform a required function (see EN 13306)

NOTE 1 After failure the item has a fault which may be complete or partial.

NOTE 2 "Failure" is an event, as distinguished from a "fault", which is a state.

3.1.12**failure cause**

circumstances during design, manufacture or use which have led to a failure (see ISO 14224)

3.1.13**failure impact**

impact of a failure on an equipment's function(s) or on the plant (see ISO 14224)

NOTE On equipment level, failure impact can be classified in three classes: critical, degraded, and incipient.

3.1.14**failure mechanism**

physical, chemical or other processes which lead or have led to failure (see EN 13306)

3.1.15**failure mode**

effect by which a failure is observed on the failed item (see ISO 14224)

3.1.16**failure rate**

number of failures of an item in a given time interval divided by the time interval (see EN 13306)

NOTE 1 This value is an approximation.

NOTE 2 In some cases time can be replaced by units of use.

NOTE 3 In most cases $1/MTTF$ (where MTTF is mean time to failure) can be used as the predictor for the failure rate, i.e. the average number of failures per unit time in the long run if the units are replaced by an identical unit at failure. Failure rate can be based on operational or calendar time.

3.1.17**fault**

state of an item characterized by inability to perform required function, excluding such inability during PM or other planned actions, or due to lack of external resources (see ISO 14224)

3.1.18**generic maintenance concept****GMC**

set of maintenance actions, strategies and maintenance details, which demonstrates a cost efficient maintenance method for a defined generic group of equipment functioning under similar frame and operating conditions

3.1.19**hazard**

potential source of harm (see ISO 17776)

NOTE In the context of this NORSOK standard, the potential harm may relate to human injury, damage to the environment, damage to property, or a combination of these.

3.1.20**hidden failure**

failure that is not immediately evident to operations and maintenance personnel (see ISO 14224)

NOTE Equipment that fails to perform an "on demand" function falls into this category. It is necessary that such failures be detected to be revealed.

3.1.21**inspection**

activity carried out periodically and used to assess the progress of damage in a component

NOTE 1 Inspection can be by means of technical instruments (e.g. NDT) or as visual examination.

NOTE 2 EN 13306 has been deviated from in order to apply to the most common use of the term "inspection" in the oil and gas industry, which relates inspection and inspection management to the activity of checking the conformity of the equipment by NDT instruments or visual examination at regular intervals.

3.1.22**item**

any part, component, device, subsystem, functional unit, equipment or system that can be individually considered (see EN 13306)

NOTE 1 Item is also known as tag or functional location.

3.1.23**maintainable item**

item that constitutes a part, or an assembly of parts, that is normally the lowest level in the hierarchy during maintenance (see ISO 14224)

3.1.24**maintenance**

combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function (see EN 13306)

3.1.25**maintenance effectiveness**

ratio between the maintenance performance target and the actual result (see EN 13306)

3.1.26**maintenance management**

all activities of the management that determine the maintenance objectives, strategies, and the responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvements of methods in the organisation including economical aspects (see EN 13306)

3.1.27**maintenance strategy**

management method used in order to achieve the maintenance objectives (see EN 13306)

3.1.28**may**

verbal form used to indicate a course of action permissible within the limits of this NORSOK standard

3.1.29**modification**

combination of all technical, administrative and managerial actions intended to change the function of an item (see EN 13306)

3.1.30**performance standard****PS**

the performance standard describes the role of the barrier as a risk reducing measure and its relations to other safety systems managing a potential hazard. The performance standard outlines the requirements of the specific system in terms of its functionality (i.e. the essential duties that the system is expected to perform), integrity (i.e. reliability and availability parameters of the particular barrier) and survivability (i.e. the functionality of the barrier under the conditions of a major accident when the system is required to operate)

3.1.31**preventive maintenance****PM**

maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the function of an item (see EN 13306)

3.1.32**production assurance**

activities implemented to achieve and maintain a performance that is at its optimum in terms of the overall economy and at the same time consistent with applicable framework conditions (see ISO 20815)

3.1.33**redundancy**

existence of more than one means at a given instant of time for performing a required function in an item (see EN 13306)

NOTE 1

Active redundancy; redundancy wherein all means for performing a required function are intended to operate simultaneously.

NOTE 2

Standby redundancy; redundancy wherein a part of the means for performing a required function is intended to operate, while the remaining part(s) of the means are inoperative until needed.

3.1.34**reliability centred maintenance****RCM**

method to identify and select failure management policies to efficiently and effectively achieve the required safety, availability and economy of operation (see IEC 60300-3-11)

3.1.35**repair time**

part of active corrective maintenance item during which repair is carried out on an item (see EN 13306)

3.1.36**risk**

combination of the probability of an event and the consequences of the event (see ISO 17776)

3.1.37**risk based inspection****RBI**

risk assessment and management process that is focused on loss of containment of pressurized equipment in processing facilities, due to material deterioration

NOTE These risks are managed primarily through equipment inspection (see API RP 580).

3.1.38

safety function

physical measures which reduce the probability of a situation of hazard and accident occurring, or which limit the consequences of an accident (see NORSOK S-001)

3.1.39

safety system

system which realises one or more active safety functions.

3.1.40

shall

verbal form used to indicate requirements strictly to be followed in order to conform to this NORSOK standard and from which no deviation is permitted, unless accepted by all involved parties

3.1.41

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

3.1.42

unsafe failure modes

failure modes dangerous to personnel but which do not threaten the MF of the equipment

3.2 Abbreviations

API	American Petroleum Institute
BoM	bill of material
BS	British Standard
CMMS	computerized maintenance management system
DNV	Det Norske Veritas
EN	European Standard
FMECA	failure mode, effect and criticality analysis
GMC	generic maintenance concept
HSE	health, safety and environment
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
KPI	key performance indicator
MF	main function
NDT	non destructive testing
OLF	Oljeindustriens Landsforening
OREDA®	offshore and onshore reliability data
P&ID	process and instrumentation diagram
PM	preventive maintenance
PS	performance standard
PSA	Petroleum Safety Authority
PU	parallel unit
QRA	quantitative risk analysis
RBI	risk based inspection
RCM	reliability centred maintenance
SAR	safe analysis report
SIL	safety integrity level

4 Methodology for risk based maintenance management

4.1 General

Risk assessment shall be used as the guiding principle for maintenance decisions. This NORSOK standard describes how to apply this in an efficient manner. The key elements of this methodology are as follows:

- a) consequence classification of functional failure;
- b) use of GMCs in combination with classical RCM methods. The GMCs are developed by RCM analysis including plant experience. The GMCs will implicitly express the probability of failure via the maintenance tasks and the maintenance interval assigned. It is recommended that the GMCs are adjusted to the local conditions via a cost-benefit assessment and including other local conditions;
- c) in case no GMCs are applicable or the purpose of the study requires more in-depth evaluations, an FMECA/RCM/RBI analysis should be carried out. Identification of relevant failure modes and estimation of failure probability should primarily be based on operational experience of the actual equipment. Alternatively generic failure data from similar operations may be used with sufficient reliability data qualification in accordance with ISO 20815, Annex E.2;
- d) the application of the consequence classification and additional risk factors for decision making related to corrective maintenance and handling of spare parts.

As important as the risk assessment, is having well defined work processes and company/management commitment. This NORSOK standard describes the main work flow and sets minimum requirements to each of the steps in this process. Further the process points out the importance of continuous improvement based on reporting and analysis of the plant condition.

4.2 Safety functions

Establishment of function requirements for the safety functions should be based on risk evaluations of accidental events, which will determine the safety systems and their performance. The overall performance shall be documented in the form of PSs or equivalent. The PS will set requirements with respect to availability, capacity and performance of safety functions. Reference is made to NORSOK S-001, ISO 13702, IEC 61508, IEC 61511, OLF 070 and ISO 20815. ISO 14224, F.3, lists the most common safety systems/components for an oil and gas installation with definition of critical/dangerous failure modes.

One of the most important tasks for the maintenance organisation is to maintain this performance during the lifecycle of the plant. Availability requirements should be used to determine the programme for PM activities and the required contingency plans in the event of failure.

The inherent availability of the safety functions should be controlled and documented. The development of failure rate and system unavailability should be used as the basis for changing of test intervals and other mitigating actions to ensure compliance with function requirements.

4.3 Static process equipment

Static process equipment (containment function) has a dual function, i.e. a safety function related to leak failures and a production function related to storing and transporting gas or liquids, see Clause 7.

In order to establish an inspection programme for this equipment, it is necessary to perform detailed evaluations similar to an FMECA, usually named RBI. The process requires knowledge of

- damage mechanism which depends on material properties, internal fluid compositions and the external operational environment – determining the probability of failure,
- consequence of leak failure with respect to personnel, environment damages and financial losses

The combination of the above represents the risk of failure which should be mitigated.

The consequence classification methodology could be applied for screening of static mechanical equipment with the purpose of excluding non-critical equipment for further analysis and prioritise other equipment for in-depth risk evaluations as the basis for preparation of inspection programmes. The result of the RBI process is determination of

- location and extent of inspections and condition monitoring,
- inspection methods,
- inspection intervals.

There exist several standards for performing RBI analysis depending on type of object. Reference is made to DNV RP-G-101 for topside systems, DNV RP-F-206 for risers, and DNV RP-F116 for submarine pipeline systems. For refineries the API RP 580 can be applied.

4.4 Risk decision criteria

Risk based decisions have to be done against defined criteria. The definition of the criteria should be done in accordance with overall company policy for HSE, production and cost. The criteria shall be properly defined and communicated.

This NORSOK standard will not define any generic criteria, but describe an example of such criteria. See also NORSOK Z-013 and ISO 17776. The level of detailing in any risk matrix used is company specific, and can typical vary from a course 3x3 matrix to 5x10.

The following principles should apply:

- the risk matrix should as far as possible be the same for all operation for a company in order to aid common companywide optimisation and devote resources accordingly as well as having a common language for communicating risk;
- further, the same criteria should be used for all equipment and systems (also those excluded from this standard). This is in particular important for topside maintenance and inspection planning which are handling basically the same hardware;
- the consequence of loss of functionality (both loss of MF and sub functions) should take into account the standby redundancy (see 3.1.33) and reduce the impact accordingly.

Annex C gives example of criteria which can be used for classification, development of preventive work tasks and for prioritisation of work orders, as well as for optimisation of spares.

5 Maintenance management – Application of consequence classification

The purpose of this clause is

- to describe the key elements and expectations of the overall maintenance management work process,
- to describe where consequence classification is applicable in the maintenance management work process,
- highlight how risk management aspects are taken into account in the different steps in the process,
- link the main steps to the rest of the document where risk assessment details are described.

This description is not a comprehensive description of maintenance management in its wider sense. However, it gives a short description of what each step typically involves.

Maintenance management is illustrated as a work process where products are produced with low HSE risks and high production performance. The basic model proposed as industry best practice is shown in Figure 1².

On an overall level there are resources, management of work processes and results. Each of the elements in the management process may be detailed into a set of sub processes and products. In the following a brief description of the different elements in the maintenance management process is given. Those elements, where risk assessment, use of consequence classification and probability for failure assessment are important, are further described in this document and referenced below.

² The model is based on PSA "Basisstudie" from 1998

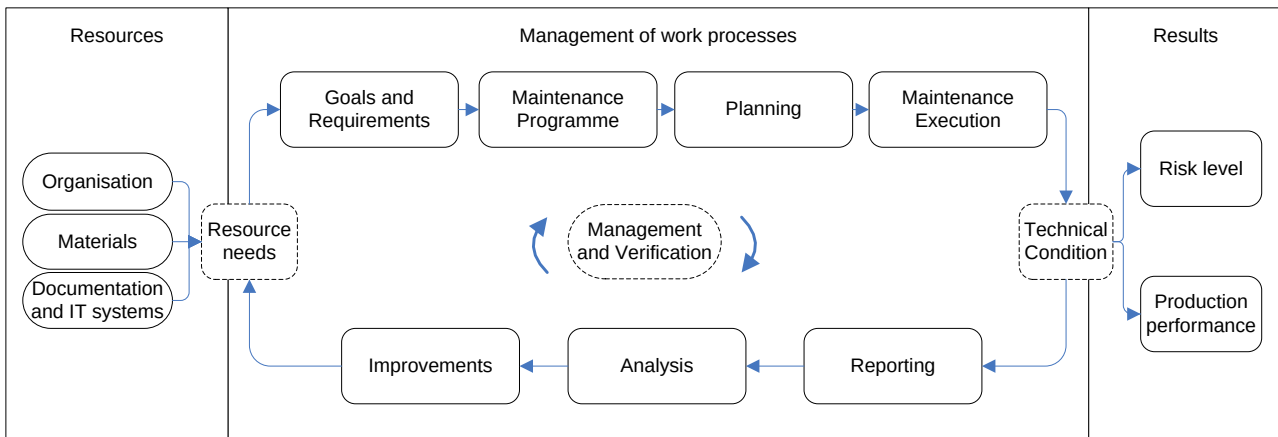


Figure 1 – Maintenance management process

Goals and requirements:

Goals should be established that commit the organisation to a realisable level of performance. The goals should focus on ambition level for

- risk, production and cost,
- regulatory requirements,
- technical condition of the facility in particular the performance of safety systems and critical processes,
- improvement of overall maintenance process.

Maintenance strategies should be defined for the asset.

Maintenance programme:

Failure modes, failure mechanisms and failure causes that can have a significant effect on safety and production shall be identified and the risk determined in order to establish a maintenance programme. The maintenance programme includes maintenance interval and written procedures for maintaining, testing, and preparing the various components within the plant.

This activity will typically involve the following:

- performing consequence classification for functions. The consequence class is inherited by the equipment relevant for the function;
- for equipment representing high consequence in case of failure, the failure mode, failure cause and the connected maintenance programme should be developed, documented and made traceable;
- safety barriers and/or safety functions should be identified, reliability requirements defined for the functions, and a testing programme to maintain the functionality should be developed;
- criteria for when the maintenance programme are to be updated based on time, experienced failures or similar should be defined. In particular failures of safety critical systems shall be analysed and the programme updated on a regular basis.

See Clause 7 and Clause 8.

Planning:

A maintenance plan is a structured set of tasks that include the activities, procedures, resources and the time required to carry out maintenance. Planning consists of budgeting, long term planning, day to day planning and prioritising.

This will typically involve the following:

- have a defined method and criteria for planning and prioritising of both preventive and corrective work based on its impact on HSE and production;
- the plans are regularly monitored and reviewed to assess achievement, backlog, and efficiency.