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Foreword

NORSOK Z-008:2024 was adopted as NORSOK standard and published 2024-xx-xx.

NORSOK Z-008:2024 supersedes NORSOK Z-008:2017.

NORSOK is an acronym for the competitive position of the Norwegian continental shelf and comprise petroleum industry standards in Norway. The collaboration initiative in 1993 between the authorities and the petroleum industry initiated the development of NORSOK standards.

Reducing the project execution time and developing and operating cost for petroleum installations on the Norwegian shelf was the target.

The intention for the Petroleum industry is to develop and use standards providing good technical and cost effective solutions to ensure that the petroleum resources are exploited and managed in the best possible way by the industry and the authorities. The industry will actively contribute to the development and use of international standards in the global market.

The NORSOK standards shall:

— bridge the gap based on experiences from the Norwegian continental shelf where the international standards are unsatisfactorily;

— replace oil company specifications where possible;

— be available as references for the authorities' regulations;

— be cost effective;

— promote the Norwegian sector as an attractive area for investments and activities.

Developing new NORSOK standards and regular maintenance of existing standards shall contribute to maintain the competitiveness both nationally and internationally for the Norwegian petroleum industry.

The NORSOK standards are developed by experts from the Norwegian petroleum industry and approved according to the consensus principles as laid down by the guidelines given in NORSOK A-001 directive.

The NORSOK standards are owned by Offshore Norge, the Federation of Norwegian Industries and the Norwegian Shipowners' Association. They are managed and published by Standards Norway.

Annex A, B, C, D and E are informative.

The following has been changed since last edition:

— Simplified descriptions regarding technical safety are available and maintained in other standards.

— Updated and added information for the functional classification work process regarding inheritance rules and assigning sub functions.

— Added Annex E regarding this standards role in addressing climate change.

— Clause 8.5: Requirements for quality assurance between the results for the consequence classificaiton and the technical barrier element analysis.

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Introduction

This document provides requirements and guidelines for:

— establishment of technical hierarchy;

— consequence classification of equipment;

— how to use consequence classification in maintenance management;

— maintenance management of technical barrier elements;

— how to use risk and reliability analysis to establish and update PM programs;

— how to aid decisions related to maintenance using the underlying risk analysis;

— spare part evaluations.

This document is applicable for different purposes and life cycle phases, such as:

— **design phase**: establish initial maintenance programs as input to manning requirements and system configuration. Selection of capital spare parts;

— **preparation for operation**: development of initial maintenance programs for implementation into maintenance management systems and selection of spare parts;

— **operate:** updating and optimisation of existing maintenance programs. Guidance for prioritising work orders. Maintenance program and handling of ageing when lifetime extension;

— **cessation:** optimising maintenance program for the cessation of production and preparing the asset for decommissioning.

This document takes all risk elements that are the basis for preparation and optimisation of maintenance programs for new and in service facilities into account, i.e. risk related to:

— personnel;

— environment;

— production loss;

— direct and indirect costs, including reputation.

This document defines how risk elements are taken into account as a basis of maintenance programs. NS-EN ISO 20815:2018 provides requirements and guidance for production assurance and reliability management that will support maintenance management.[1].

The document describes the key work processes with explanations and requirements for each, and is organised in the following way, see Figure 1.

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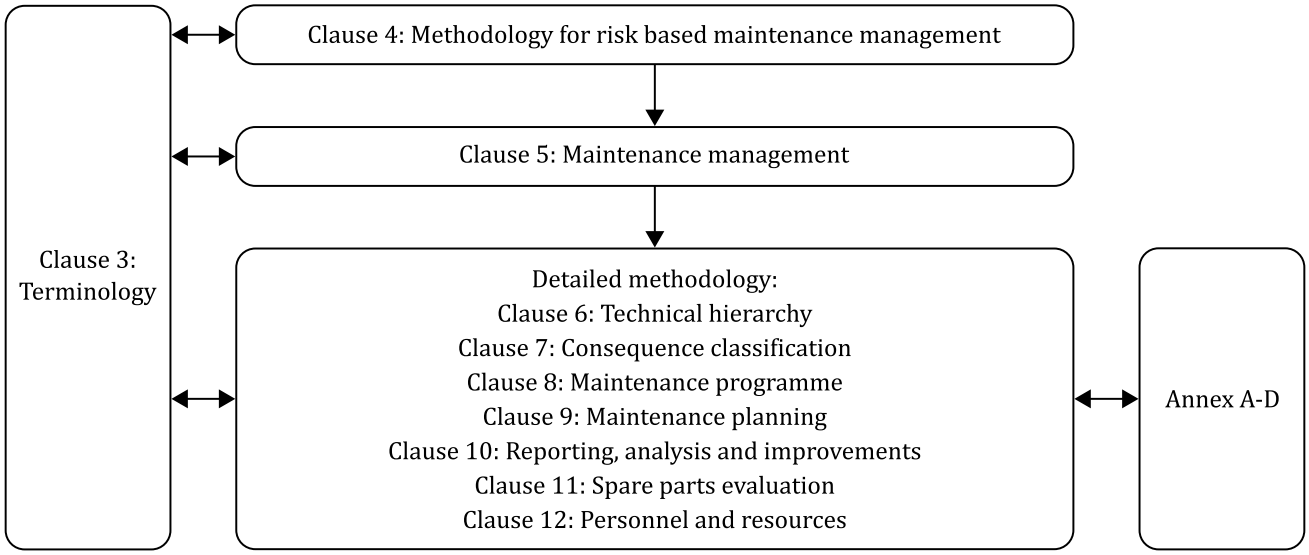


Figure 1 — Clause interrelationship in standard

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Risk based maintenance and consequence classification

1 Scope

This document is applicable for the preparation and optimisation of maintenance activities for all plant systems and items.

The principles of consequence classification and the maintenance task selection process are applicable to all types of items and all types of failure modes and failure mechanisms covered by this document. For some types of items, it is typical to perform other specific analyses to identify failure characteristics, failure frequencies and mitigating tasks. These include, among others, load-bearing structures, static pressure equipment, risers and pipelines.

This document is developed with the oil and gas industry in mind, but the principles within can be applied to any industry, including manufacturing or processing plants, ships or maritime facilities and energy plants or installations.

This document covers:

— definition of relevant nomenclature;

— brief description of the main workflow 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 SFs;

  — identification of MF and SF redundancy;

  — assessment of the consequences of loss of MFs and SFs;

  — assignment of equipment to SFs and associated consequence classes.

— description of how to establish an initial maintenance program, and how to update an existing program;

— 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 references

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

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

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3 Terms and definitions

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

3.1
can (possibility)
expression in the content of a document conveying expected or conceivable material, physical or causal outcome

Note 1 to entry: Note 1 to entry: Possibility is expressed using the verbal forms specified in ISO/IEC-Directives part 2, clause 7.5 Table 6.

3.2
can (capability)
expression in the content of a document conveying the ability, fitness, or quality necessary to do or achieve a specified thing

Note 1 to entry: Note 1 to entry: Capability is expressed using the verbal forms specified in in ISO/IEC-Directives part 2, clause 7.5 Table 6.

3.3
may (permission)
expression in the content of a document conveying consent or liberty (or opportunity) to do something

Note 1 to entry: Permissions are expressed using the verbal forms specified in ISO/IEC Directives Part 2 clause 7.4 Table 5.

3.4
should (recommendation)
expression in the content of a document conveying a suggested possible choice or course of action deemed to be particularly suitable without necessarily mentioning or excluding others

Note 1 to entry: Recommendations are expressed using the verbal forms specified in ISO/IEC Directives, Part 2 clause 7.3 Table 4.

Note 2 to entry: In the negative form, a recommendation is the expression that a suggested possible choice or course of action is not preferred but it is not prohibited.

3.5
shall (requirement)
expression in the content of a document conveying objectively verifiable criteria to be fulfilled and from which no deviation is permitted if compliance with the document is to be claimed

Note 1 to entry: Requirements are expressed using the verbal forms specified in ISO/IEC Directives, Part 2 clause 7.2 Table 3.

3.6
active repair time
effective time to achieve repair of an item

Note 1 to entry: See also SN-CEN ISO/TR 12489:2016 [2] Figures 5 and 6

Note 2 to entry: See also definition of "mean active repair time (MART)" in SN-CEN ISO/TR 12489:2016 [2] 3.1.34, that is defined as "expected active repair time".

[SOURCE: NS-EN ISO 14224:2016]

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3.7
availability
ability to be in a state to perform as required

Note 1 to entry: See NS-EN ISO 14224:2016 Annex C for a more detailed description and interpretation of availability.

Note 2 to entry: Further terms are given in SN-CEN ISO/TR 12489:2016 [2].

[SOURCE: NS-EN ISO 14224:2016 3.3]

3.8
barrier
functional grouping of safeguards or controls selected to prevent a major accident or limit the consequences

Note 1 to entry: Barriers can be subdivided into technical, operational and organisational barrier elements.

Note 2 to entry: This document focuses on technical barrier elements.

[SOURCE: NS-EN ISO 17776:2016 [3] 3.1.1, Note 1 to entry modified. Note 2 to entry deleted from source and replaced with new text]

3.9
condition-based maintenance
preventive maintenance based on the assessment of physical condition

Note 1 to entry: The condition assessment can be by operator observation, conducted according to a schedule, or by condition monitoring of system parameters.

[SOURCE: NS-EN ISO 14224:2016 3.7]

3.10
condition monitoring
obtaining information about physical state or operational parameters

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

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

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

[SOURCE: NEK IEC 60050-192:2015 [4], 192-06-28, modified — Note 3 to entry has been added]

3.11
consequence
outcome from an event

Note 1 to entry: 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.

Note 2 to entry: Annex C.2 and NS-EN ISO 14224:2016 Annex C.1.10 give examples of consequence classification.

Note 3 to entry: See also definition of *failure impact* (3.23).

[SOURCE: ISO/TS 18683:2021 [5]]

3.12
consequence classification
qualitative analysis of events and failures and assignment of the consequences of these.

Note 1 to entry: See definitions of *consequence HSE ()*, *consequence production ()* and *consequence other ()*.

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3.16
corrective maintenance
CM
maintenance carried out after fault detection to affect restoration

Note 1 to entry: See also SN-CEN ISO/TR 12489:2016 [2] Figures 5 and 6, which illustrate terms used for quantifying corrective maintenance.

[SOURCE: NS-EN ISO 14224:2016 3.8, Note 1 to entry deleted from source]

3.17
critical failure
failure of an equipment unit that causes an immediate cessation of the ability to perform a required function

Note 1 to entry: Includes failures requiring immediate action towards cessation of performing the function, even though actual operation can continue for a short period of time. A critical failure results in an unscheduled repair.

[SOURCE: NS-EN ISO 14224:2016 3.9, Note 2 to entry deleted from source]

3.18
degraded failure
failure that does not cease the fundamental function(s), but compromises one or several functions

Note 1 to entry: The failure can be gradual, partial or both. The function can be compromised by any combination of reduced, increased or erratic outputs. An immediate repair can normally be delayed but, in time, such failures can develop into a critical failure if corrective actions are not taken.

[SOURCE: NS-EN ISO 14224:2016 3.11]

3.19
equipment class
class of similar type of equipment units (e.g. all pumps)

Note 1 to entry: NS-EN ISO 14224:2016 Annex A contains equipment-specific data for the equipment covered in this International Standard

Note 2 to entry: NS-EN ISO 14224:2016 Annex A provides a list of equipment classes.

[SOURCE: NS-EN ISO 14224:2016 3.18, Note 1 to entry modified.]

3.20
failure
<of an item> loss of ability to perform as required

Note 1 to entry: A failure of an item is an event that results in a fault of that item: see *fault* (3.27).

Note 2 to entry: A failure of an item is an event, as distinct from a fault of an item, which is a state [SN-CEN ISO/TR 12489:2016 [2]].

[SOURCE: NS-EN ISO 14224:2016 3.23]

3.21
failure cause
circumstances during specification, design, manufacture, installation, use or maintenance that result in failure

Note 1 to entry: See also NS-EN ISO 14224:2016 B.2.3 and Table B.3 which define failure causes for all equipment classes.

[SOURCE: NS-EN 13306:2017 [6] 5.3, Note 1 to entry added]

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3.22
failure frequency
unconditional failure intensity; conditional probability per unit of time that the item fails between t and t + dt, provided that it was working at time 0

Note 1 to entry: Another term used for failure frequency is “rate of occurrence”.

Note 2 to entry: See NS-EN ISO 14224:2016 C.3 with respect to failure rate and failure frequency estimations.

Note 3 to entry: Note the difference between failure rate and failure frequency. Failure rate is defined in NS-EN ISO 14224:2016 3.32.

[SOURCE: NS-EN ISO 14224:2016 3.27, Note 2 to entry modified, Note 3 to entry has been added]

3.23
failure impact
effect of a failure on an equipment's function(s) or on the plant

Note 1 to entry: On the equipment level, failure impact can be classified in three classes (critical, degraded and incipient); see definitions of “critical failure”, “degraded failure” and “incipient failure” in NS-EN ISO 14224:2016 3.9, 3.11, and 3.40.

[SOURCE: NS-EN ISO 14224:2016, 3.28, modified - Note 1 to entry has been deleted]

3.24
failure mechanism
physical, chemical or other processes which may lead or have led to failure

Note 1 to entry: See also NS-EN ISO 14224:2016 B.2.2 and Table B.2, which define failure causes for all equipment classes.

[SOURCE: NS-EN 13306:2017 [6] 5.13, Note 1 to entry added]

3.25
failure mode
manner in which the inability of an item to perform a required function occurs

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

[SOURCE: NS-EN 13306:2017 [6] 5.2, Note 1 to entry deleted from source and replaced with new text]

3.26
failure rate
conditional probability per unit of time that the item fails between t and t + dt, provided that it has been working over [0,t]

Note 1 to entry: See also definition of failure rate in SN-CEN ISO/TR 12489:2016 [2] 3.1.18.

Note 2 to entry: See NS-EN ISO 14224:2016 C.3 with respect to failure rate and failure frequency estimations.

Note 3 to entry: Note the difference between failure rate and failure frequency. Failure frequency is defined in NS-EN ISO 14224:2016 3.27.

[SOURCE: NS-EN ISO 14224:2016 3.32, modified -Original Note 2 to entry has been deleted. New Note 2 and Note 3 to entry have been added]

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3.27
fault
inability to perform as required, due to an internal state

Note 1 to entry: A fault of an item results from a failure, either of the item itself, or from a deficiency in an earlier stage of the life cycle, such as specification, design, manufacture or maintenance. See also latent fault (NS-EN ISO 14224:2016 3.44).

Note 2 to entry: A fault is often a result of a failure of the item itself but the state can exist without a failure (see ISO 20815:2018 [7] 3.1.14).

Note 3 to entry: See also SN-CEN ISO/TR 12489:2016 [2] 3.2.2.

[SOURCE: NS-EN ISO 14224:2016 3.33]

3.28
GMC
generic maintenance concept
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

3.29
hazard
potential source of harm

Note 1 to entry: In the context of this document, the potential harm may relate to human injury, damage to the environment, damage to property, or a combination of these.

[SOURCE: NS-EN ISO 17776:2016 [3] 3.1.8, Note 1 to entry added]

3.30
hidden failure
failure that is not immediately evident to operations and maintenance personnel

Note 1 to entry: Equipment failures that occurred at an earlier point of time, but were first observed at demand, fall into this category. Such failures are first revealed when the relevant functionality is tested (activated).

Note 2 to entry: See definition with notes to entry in SN-CEN ISO/TR 12489:2016 [2] 3.2.11.

Note 3 to entry: See also latent fault (NS-EN ISO 14224:2016 3.44).

[SOURCE: NS-EN ISO 14224:2016 3.35]

3.31
incipient failure
imperfection in the state or condition of an item so that a degraded or critical failure might (or might not) eventually be the expected result if corrective actions are not taken

Note 1 to entry: The recording of incipient failure requires some criteria for when a fault of this nature requires registration as opposed to a state or condition where no corrective actions are required.

[SOURCE: NS-EN ISO 14224:2016 3.40]

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3.32
inspection
activity carried out periodically and used to assess the progress of damage in a component

Note 1 to entry: Inspection can be by means of technical instruments (e.g. NDT) or as visual examination.

Note 2 to entry: This document uses the common 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.

[SOURCE: DNV-RP-G101 [8]]

3.33
item
subject being considered

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

[SOURCE: NS-EN ISO 14224:2016 3.43, Note 2 and 3 to entry have been deleted]

3.34
MF
main function
principal tasks in a system being considered

Note 1 to entry: Annex A gives an overview of typical MFs for an oil and gas production plant.

3.35
maintainability
<of an item> ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance

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

Note 2 to entry: See also NS-EN ISO 14224:2016 Annex C for a more detailed definition and interpretation of maintainability.

[SOURCE: NS-EN ISO 14224:2016 3.47 Note 2 to entry modified, Note 3 to entry deleted from source]

3.36
maintainable item
item that constitutes a part, or an assembly of parts that is normally the lowest level in the equipment hierarchy during maintenance

[SOURCE: NS-EN ISO 14224:2016 3.48]

3.37
maintenance
combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required

Note 1 to entry: NS-EN ISO 14224:2016 Figure 6 shows the main maintenance categories in more detail. NS-EN NS-EN ISO 14224:2016 Table B.5 presents the main types of maintenance activities commonly performed.

[SOURCE: NS-EN ISO 14224:2016 3.49, Note 1 to entry has been modified]

3.38
maintenance effectiveness
ratio between the maintenance actual result and performance target

Note 1 to entry: See examples of KPIs in Clause 10 and NS-EN ISO 14224:2016 Annex E that can be used for measure of maintenance effectiveness.

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3.36
maintenance engineering
engineering discipline applying competencies, methods, techniques and tools to develop and support maintenance in order to assure that an item is able to perform its required functions in a safe, sustainable and cost-effective manner throughout the life cycle

[SOURCE: NS-EN 17666 [9]]

3.39
maintenance management
all activities of the management that determine the maintenance requirements, objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics

[SOURCE: NS-EN 13306:2017 [6] 2.2]

3.40
maintenance strategy
management method used in order to achieve the maintenance objectives

[SOURCE: NS-EN 13306:2017 [6] 2.4]

3.41
modification
combination of all technical and administrative actions intended to change an item

Note 1 to entry: Modification is not normally a part of maintenance, but is frequently performed by maintenance personnel.

Note 2 to entry: Care is needed to distinguish between maintenance due to failures and maintenance due to equipment modification.

[SOURCE: NS-EN ISO 14224:2016 3.67, Note 2 to entry modified, Note 3 to entry deleted from source]

3.40
performance requirement
required minimum level for the performance of a system

Note 1 to entry: Requirements are normally expressed in quantitative terms, but may also be expressed in qualitative terms

3.42
PS
performance standard
measurable statement, expressed in qualitative or quantitative terms, of the performance required of a system, item of equipment, person or procedure, and that is relied upon as a basis for managing a hazard

Note 1 to entry: Hardware performance standards address the functionality, reliability, survivability and interdependency of barriers under emergency conditions.

[SOURCE: NS-EN ISO 17776:2016 [3] 3.1.16]

3.43
predictive maintenance
maintenance based on the prediction of the future condition of an item estimated or calculated from a defined set of historic data and known future operational parameters

[SOURCE: NS-EN ISO 14224:2016 3.77, Note 1 to entry deleted from source]

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3.44
preventive maintenance
PM
maintenance carried out to mitigate degradation and reduce the probability of failure

Note 1 to entry: Preventive maintenance contains condition-based maintenance and predetermined maintenance, see NS-EN ISO 14224:2016 Figure 6.

[SOURCE: NS-EN ISO 14224:2016 3.78, Note 1 to entry modified]

3.45
production assurance
activities implemented to achieve and maintain a performance that is at its optimum in terms of the overall economy and at the same time consistent with applicable framework conditions

[SOURCE: NS-EN ISO 20815:2018 [1] 3.1.45, Note 1 and Note 2 deleted from source]

3.46
redundancy
existence of more than one means for performing a required function of an item

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

Note 2 to entry: Redundancy in NEK IEC 61508 (all parts) [10] is called “fault tolerance”.

[SOURCE: NS-EN ISO 14224:2016 3.80, Note 3 to entry has been deleted.]

3.47
reliability
ability of an item to perform a required function under given conditions for a given time intervalability of an item to perform a required function under given conditions for a given time interval

[SOURCE: NS-EN ISO 14224:2016 3.81, Note 1, Note 2, Note 3 and Note 4 to entry deleted from source]

3.48
required function
function or combination of functions of an item that is considered necessary to provide a given service

[SOURCE: NS-EN ISO 20815:2018 [1] 3.83]

3.49
risk
combination of the probability of an event and the consequence of the event

Note 1 to entry: See further important information regarding definition of risk in NS-EN ISO 20815:2018 [1].

[SOURCE: NS-EN ISO 20815:2018 [1] 3.54, modified - Original Note 1 and Note 2 to entry have been deleted. New Note 1 to entry has been added.]

3.50
safety system
system which is used to implement one or more safety functions

Note 1 to entry: Safety function is in SN-CEN ISO/TR 12489:2016 [2] 3.1.6 defined as “function which is intended to achieve or maintain a safe state, in respect of a specific hazardous event’.

Note 2 to entry: Systems with safety functions are defined in SN-CEN ISO/TR 12489:2016 [2] Annex A. These systems are also cross-related in NS-EN ISO 14224:2016 Table A.3.

[SOURCE: NS-EN ISO 14224:2016 3.86]

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3.51
SF
sub function
grouping of items performing the same function within a main function

Note 1 to entry: See Annex B for a list of standardized SFs.

3.52
tag number
unique code that identifies the equipment function and its physical location

[SOURCE: NS-EN ISO 14224:2016 3.91, Note 1, Note 2, Note 3 and Note 4 to entry deleted from source]

3.53
unsafe failure
failure of a safety system which tends to impede a given safety action

Note 1 to entry: When dealing with safety instrumented systems, unsafe" is synonymous with "dangerous".

Note 2 to entry: An unsafe failure of an item is not necessarily a critical failure of the item. See further information in Clause 8.3.

[SOURCE: SN-CEN ISO/TR 12489:2016 [2] 3.2.3]

4 Abbreviations

For this document, the following symbols and abbreviations apply:

BoM	bill of material
CMMS	computerized maintenance management system
FMECA	failure mode, effect and criticality analysis
GHG	greenhouse gas
GMC	generic maintenance concept
HSE	health, safety, and environment
KPI	key performance indicator
LCI	life cycle information
OEM	original equipment manufacturer
OPEX	operational expenditure
OREDA®	Offshore & Onshore Reliability data
P&ID	piping and instrumentation diagram
PFD	probability failure on demand
PU	parallel units
RBI	risk based inspection
RCM	reliability centered maintenance

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QRA quantitative risk assessment

SIL safety integrity level

5 Methodology for risk based maintenance management

5.1 General

Risk assessment shall be used as the guiding principle for maintenance decisions. Well-defined work processes and company or management commitment are equally important to the risk assessment and shall be implemented and available.

This document recommends the following risk-based maintenance procedures:

a) Consequences classification of functional failure.

b) A risk-based maintenance task selection process. Identification of relevant failure modes and estimation of failure probability is primarily based on the operational experience of the actual equipment. Alternatively, generic failure data from similar operations is used with sufficient reliability data qualification in accordance with NS-EN ISO 20815:2018 [1] Annex E.2.

c) 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. GMCs are typically adjusted to the local conditions via a cost-benefit assessment and include other local conditions.

d) A more detailed analysis, such as FMECA, RCM or RBI, shall be carried out in case no GMCs are applicable or the purpose of the study requires more in-depth evaluations.

e) Application of the consequence classification and additional risk factors for decision-making related to corrective maintenance and handling of spare parts.

This document describes the main workflow and sets minimum requirements for 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.

5.2 Technical barrier elements

Requirements for technical barrier elements and their performance standards (PS) are provided in NS-EN ISO 17776:2016 [3] and NORSOK S-001 [11]. The performance standards define the required performance of barrier functions with respect to availability and capacity. The principles in NS-EN ISO 14224:2016 shall be applied for reliability data used for defining the performance standards of the barriers.

See Clause 8 for the consequence classification of technical barrier elements.

See 9.3 for maintenance of technical barrier elements.

See Clause 11 for more information regarding reporting requirements.

5.3 Process systems with containment function

Process systems have multiple functions, i.e. a function related to processing and transporting gas or liquids and a containment function related to preventing external leakage of gas and liquids. The functional requirements for the storing or transporting of gas and liquids are covered in Clause 8.

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Detailed evaluations similar to an FMECA and RCM process, usually named RBI, shall be performed in order to establish an inspection program for the containment function of the equipment.The process requires knowledge of:

— failure mechanism, which depends on material properties, internal fluid compositions and the external operational environment – determining the probability of failure, and

— consequences of leakage with respect to personnel, environmental damages and financial losses.

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

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

— location and extent of inspections and condition monitoring;

— inspection methods;

— inspection intervals.

Several documents for performing RBI methodology are available, depending on the type of object:

— DNV-RP-G101 [12] for topside systems;

— DNV-RP-F206 [13] for risers;

— DNV-RP-F116 [14] for submarine pipeline systems;

— DNV-RP-0002 [15] for subsea production systems;

— API RP 580 [16] for refineries.

5.4 Risk decision criteria

Risk-based decisions shall be made in accordance with defined criteria. The definition of the criteria should be in accordance with overall company policy for HSE, production and cost.The criteria shall be properly defined and communicated to all personnel involved in risk decisions, including operational personnel.

NOTE Examples of criteria for risk-based decisions are given in Annex C. The level of detailing in any risk matrix used is company-specific and can typically vary from a course 3x3 matrix to a more detailed 5x10 matrix.

The following principles for risk-based decisions should apply:

— The consequence- and risk matrices used for maintenance purposes should, as far as possible, be aligned with the overall company risk matrices. These can be customised for maintenance purposes to aid proper planning and prioritising of maintenance activities and be the same for all operations for a company in order to aid common companywide optimisation and allocate resources accordingly, as well as having a common terminology for communicating risk.

— The same criteria should be used for all equipment and systems (also for equipment covered by other standards, such as load-bearing structures, risers and pipelines). This is particularly important for topside maintenance and inspection planning, which are handling the same equipment.

Annex C gives examples of criteria that can be used for classification, development of preventive work tasks, prioritisation of work orders, and optimisation of spare parts.

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5.5 Input to maintenance engineering

Maintenance engineering and the development of a maintenance program should be considered part of the design premises in an early stage of a project phase, as decisions done in design will influence the level and type of maintenance necessary to perform when in operation.

The design's effect on reliability, operation, maintainability and level of maintenance should be considered in all phases of design.

EXAMPLE Examples of relevant studies that can have input to the maintenance engineering include:

- barrier analyses (performance standards, see NORSOK S-001 [11] or NS-EN ISO 13702 [17]);
- safety integrity level analyses (see NEK IEC 61508 (all parts) [10] or NEK IEC 61511 (all parts) [18], ON 70 [19]);
- production availability & reliability analyses (see NS-EN ISO 20815:2018 [1]);
- risk-based inspection analyses (see DNV-RP-G101 [12]);
- life cycle cost or profit (see NS-EN ISO 15663[20]);
- maintainability studies;
- working environment studies (see NORSOK S-002 [21]);
- material handling studies;
- manning studies;
- HAZOP (see NS-EN ISO 20815:2018 [1]).
- Risk assessment in the management of major accident risk process (see NORSOK Z-013 [22])

6 Maintenance management

6.1 General

The purpose of this clause is to:

- describe the key elements and expectations of the overall maintenance management work process,
- 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, and
- 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 outcome or results where products are produced with low HSE risks and high production performance. The basic model proposed as industry best practice is shown in Figure 2.

On an overall level, there are resources, management of work processes and results. Each of the elements in the management process can be detailed into a set of sub–processes and products. In the following, a brief description of the different elements of 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.

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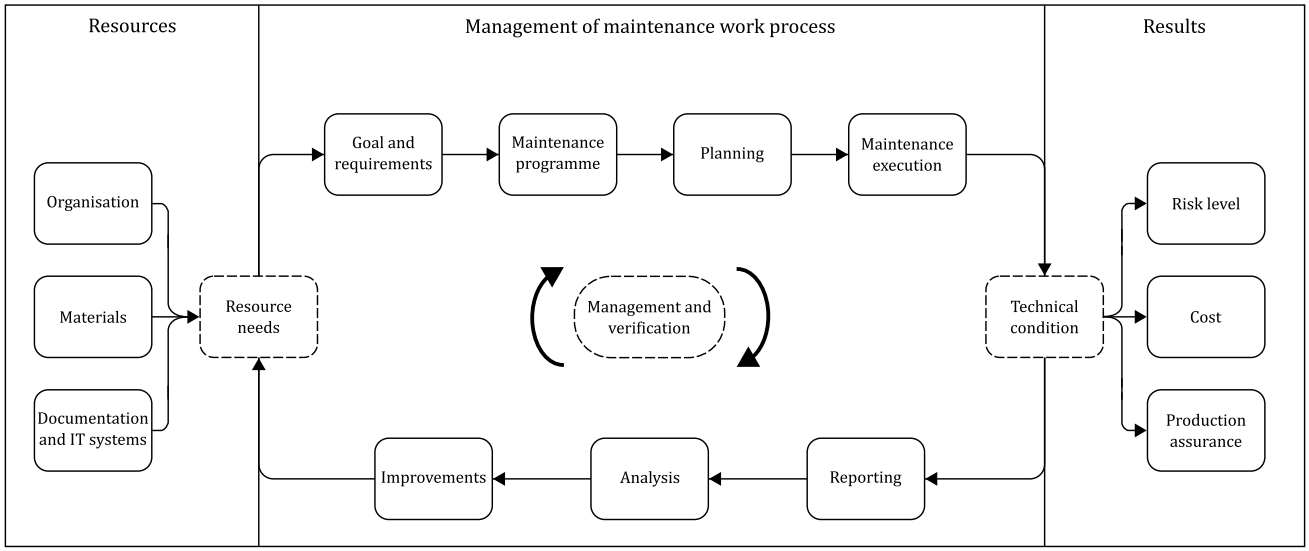


Figure 2 — Maintenance management process

6.2 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 level, production assurance and cost,

— regulatory requirements,

— technical condition of the facility, in particular the performance of safety systems and critical processes, and

— improvement of the overall maintenance process.

Maintenance strategies should be defined for the asset.

6.3 Maintenance program

Failure modes, failure mechanisms and failure causes that can have a significant effect on safety, health, environment, production and cost are identified and the risk determined in order to establish a maintenance program. The maintenance program includes maintenance intervals and written procedures for maintaining, testing, and preparing the various components within the plant, as well as minimum qualification of personnel.

The maintenance program shall involve the following:

— Performing consequence classification for functions. The consequence class is inherited by the equipment relevant to the function.

— For equipment representing high consequences in case of failure, the failure mode, failure cause and the connected maintenance program are developed, documented and made traceable.

— Technical barrier elements are identified, reliability requirements are defined for the functions, and a testing program to maintain the functionality is developed.

— Criteria for when the maintenance program is to be updated based on time, experienced failures or similar should be defined. In particular, failures of safety-critical systems are analysed, and the program is updated on a regular basis.

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See Clause 8 and Clause 9 for more details and requirements.

6.4 Planning

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

The maintenance plan shall involve the following:

— Have a defined method and criteria for planning and prioritising of both preventive and corrective work based on its impact on risk level, production assurance and cost.

— Group activities should be divided into efficient HSE and facility-optimal groups or packages.

— The plans are regularly monitored and reviewed to assess the level of achievement, backlog, and efficiency.

See Clause 10 for more details and requirements.

6.5 Maintenance execution

Execution includes preparations, work permits, carrying out work and reporting mandatory information on the work order. System and equipment conditions should be reported before or after repair for continuous improvement. The current operational risk assessment shall be the basis for operational priorities.

Maintenance execution shall involve the following:

— Work execution shall be performed by competent personnel according to plans, procedures and work descriptions relevant to the actual case.

— The complexity of the work (both for individual jobs and for a set of jobs) should be taken into account.

— A plan for verifying the quality of work executed should be in place.

— The condition of the equipment should be reported after completion of work. For technical barrier elements with defined reliability targets, the failure is reported to aid analysis and comparison vs. PSs.

See Clause 11 for more details and requirements.

6.6 Reporting

Reporting involves the collection and quality assurance of maintenance data and presenting these to maintenance departments and management in the form of defined indicators. In particular, technical integrity data for barrier functions shall be known and reported at appropriate levels to aid decision-making.

Reporting shall involve the following:

— Defining KPIs for monitoring and follow-up of performance.

— KPI performance outside set goals is reported and acted upon.

— Reports of safety performance, production and cost versus goals or budget should be available and communicated in the organization;

— A set of performance data shall be reported and compared to established PSs.

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See Clause 11 for more details and requirements.

6.7 Analysis and improvements

This activity involves carrying out analysis of historical maintenance data and unwanted incidents related to maintenance, e.g. trend analysis and root cause analysis. The information should be evaluated and actions suggested based on the conducted analyses should be implemented.

Analysis and improvement shall involve the following:

— A defined analysis process shall be in place, addressing trigger values, analysis techniques and responsibilities. The work should be documented and monitored.

— The analysis process shall include an evaluation of maintenance effectiveness, i.e. to what extent the maintenance program is handling the risks and performance requirements for individual systems or key components.

— The identified improvements, where actions should be implemented, and the effects should be monitored.

See Clause 11 for more details and requirements.

6.8 Organisation

The organisation consists of the people and their training, competence, job descriptions and work processes.

This will typically involve requirements for organisation, competence and roles or responsibilities.

6.9 Materials

Material resources include consumables, spare parts and tools required to carry out maintenance.

This will typically involve that the spare part availability shall be optimized based on demand, consequence of failure, repair time and cost, and linked to the maintenance planning activity.

See Clause 11 for more details and requirements.

6.10 Documentation and IT-systems

Documentation in this context includes all information required to carry out and manage maintenance in an effective manner. IT systems play a key role in Maintenance management. Those systems are normally linked to the company's ERP (Enterprise resource planning) systems. As the maintenance management process entirely relies on the good quality of the data, the process of handling, improving and managing these data at all levels is required.

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Handing data and IT systems will typically involve:

— Configuration of CMMS (Computerized Maintenance Management Systems) for efficient data management and adaptation to local regulatory requirements.

— Develop, maintain and update LCI documentation of the plant with equipment/tag register, drawings and design details.

— Handling historical maintenance data, maintenance task descriptions, spares lists, repair or replacement history, pictures, videos, surveys, etc.

— Handling updating and quality control of databases where technical information, plans and historic performance are readily available for users and decision-makers.

— Enable extraction of information from the systems, such as monitoring of the performance of the systems and estimation key performance indicators for decision-makers.

The concept of "Digital Twins" is a means of handling data, both static (design-related) and dynamic (running plant information), for efficient operation. A key element in those systems is to keep quality at all levels and over time, as well as make these data available for the end users.

6.11 Management and verification

A key to good maintenance is a well-organised management team taking responsibility for implementing the principles herein and verifying the results.The management team shall ensure that the maintenance work processes are followed.

Management and verification shall involve the following:

— The leaders shall define roles, responsibilities and qualification requirements within the area of maintenance.

— The leaders shall possess knowledge related to risk-based maintenance management and make sure that the main workflow is followed.

— The leaders shall monitor defined indicators (KPIs) and act upon deviations from set goals.

— In addition, the leaders should plan and institute audits of the organisation, suppliers and contractors.

6.12 Risk level

The risk level is a result of the operation and maintenance work done to the asset. Risk can be measured as HSE performance, technical barrier element reliability status or related indicators.

6.13 Production assurance

The plant's production assurance is a result of the 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. As indicator of this would be be achieved historic production efficiency.

6.14 Cost

Cost is here related to cost for preventive and corrective work, worked hours, spare parts and consumables which is under the control of the maintenance function.

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7 Technical hierarchy

The technical hierarchy describes the technical structure of the installation by giving physical items unique identifiers. The technical hierarchy provides an overview of equipment units that belong together technically and shows the physical relationship between main equipment, instruments, valves, etc. The technical hierarchy should be established at an early phase to give an overview of all the tags and items and how they are related. The purpose of the technical hierarchy includes:

— showing technical interdependencies of the installation;

— retrieval of tags, equipment and spare parts;

— retrieval of documents and drawings;

— retrieval of historical maintenance data from CMMS;

— planning of operations (e.g. relationships due to shutdown, etc.);

— cost allocation and retrieval;

— planning and organization of the maintenance program;

— planning of corrective work.

The level on which the maintenance objects are established is governed by practical execution and the individual needs to monitor and control the different maintenance programs. The technical breakdown of an installation should be broken down to a level where requirements and history can be linked to the individual technical barrier elements, and that the performance of the technical barrier elements can be reported and verified.

See Annex D for detailed information and practical examples of the work process for establishing a technical hierarchy.

8 Consequence classification

8.1 General

This clause describes how consequence classification shall be done, its workflow and its relation to maintenance programs. Consequence classification expresses what effect loss of function can have on HSE, production and cost/other. The classification is done according to a consequence scale, which is a part of the risk model, see Clause 8 and Annex C.

The consequence classification, together with other key information and parameters, gives input to the following activities and processes:

— selection of equipment where detailed analysis, such as FMECA, RCM or RBI, is recommended (screening process);

— establish PM program;

— preparation and optimisation of GMCs;

— design evaluations;

— prioritisation of work orders;

— spare part evaluations.

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8.2 Principles and work flow

Figure 3 shows an overall workflow related to consequence classification.

The following principles related to consequence classification shall apply:

— The consequence classification shall be done to identify critical equipment for HSE, production and cost;

— All physical tags shall be assigned a function and have a consequence classification, and no items or systems should be screened out based on an "assumed" low consequence. Administrative tags without corrective or preventive maintenance (e.g. systems, areas, equipment classes) used for establishing a technical hierarchy do not have to be classified. However, if they have preventive or corrective work orders assigned to them, they should be classified to get proper prioritization in the maintenance management system;

— All systems or tags related to an installation shall be classified using the same classification scale – regardless of which method and standard is used for the classification;

— The classification feeds into a common risk model used for operational decision-making thus they need to be comparable;

— A functional hierarchy is established (MFs and SFs). This is normally not stored in the CMMS but used during the classification process. See Clause D.2 for an example of a functional breakdown of a system. Tags or maintenance objects are assigned to the relevant SF;

— The consequence of loss of containment is assessed as a separate failure mode from the loss of function;

— Barriers are defined separately via safety analysis (e.g. quantitative risk analysis) in the design or modification process. As such, these systems and equipment are already identified and their safety function defined, almost exclusively with high consequence for HSE;

NOTE Barrier functions identified as part of a major accident hazard management process can be different from main- and SFs in the consequence classification process described in this document.

— The consequence classification only assesses the primary function of an item (i.e. pumping, storing) and not the classification of failure characteristics of a function or item, like explosion proofing, overheating, short-circuiting, which are considered as failure modes or mechanisms of the item or function. See 9.2.2 for more information.

The outcome of the classification will be a set of attributes assigned to each tag. The set of parameters shall be aligned to the decision model.

EXAMPLE Examples of information assigned to each tag are:

— functional failure or loss of function – HSE consequence,

— functional failure or loss of function – production consequence,

— functional failure or loss of function – cost/other consequence,

— consequences of loss of containment,

— barrier function identifier, and

— redundancy.

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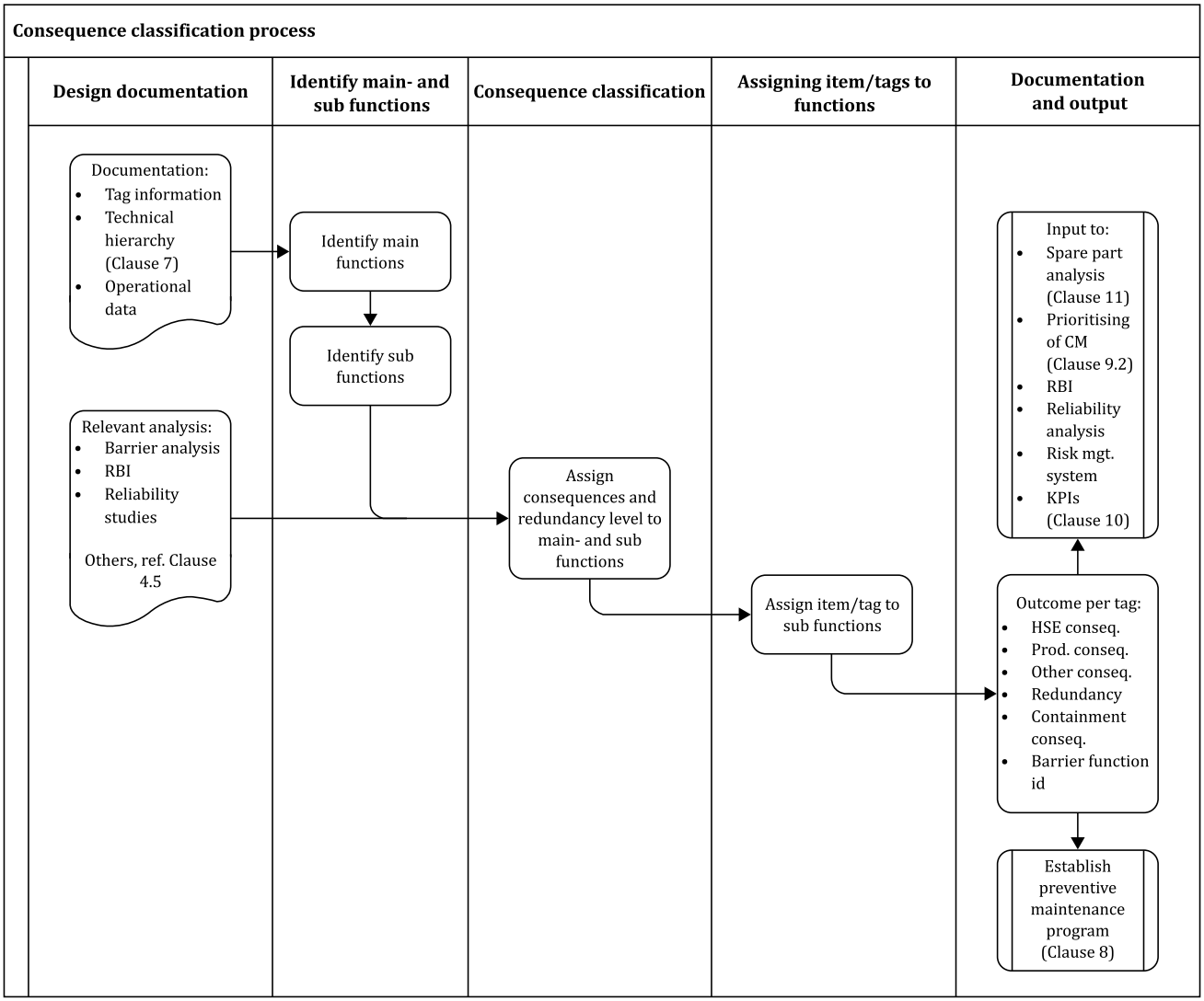


Figure 3 — Consequence classification process

8.3 Consequence classification of main and sub function

The functional classification work process is described stepwise in Table 1 and illustrated in Figure 3.

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Table 1 — Stepwise classification work process

No	Step		Activity
1	**Technical information**	—	Technical information and documentation regarding systems and items are used to identify systems and equipment which is subject to consequence classification. The Technical Hierarchy is beneficial for establishing an overview of the technical relationship between the items. See Clause 7 regarding technical hierarchy.
2	**Input from other analyses**	—	See 5.5 for information regarding documentation and relevant studies.
		—	Barriers are identified via a risk assessment where performance requirements are defined, such as reliability and survivability. In the classification process, these systems are mapped to the relevant items for ready identification in the CMMS system. The functional requirements are carried forward to the maintenance program to maintain these functions.
		—	Containment: For the tags or systems that are containment-related, results from an RBI methodology can be used as input to the consequence of loss of containment or vice versa.
		—	Availability: Production assurance studies can give input to functions critical to the operation of the installation.
3	**Identify MFs**	—	Each plant system is divided into a number of MFs covering the entire system.
		—	The MFs are characterised by being the principal tasks in the process, such as heat exchanging, pumping, separation, power generation, compressing, distributing, storing, etc. Annex A gives an overview of typical MFs for an oil and gas production plant.
		—	Each MF is given a unique designation consisting of a number (if appropriate, a tag number) and a name that describes the task and the process.
4	**Identify SFs**	—	MFs are split into SFs. In order to simplify the consequence assessment, the SF level can be standardised for typical process equipment with pre-defined terms. See Annex B.
		—	The standard list of SFs can be supplemented with other SFs relevant to the system configuration.
5	**Assign MF consequences**	—	The entire MF failure consequence is assessed in terms of the state where the MF is no longer able to perform its required functions.
		—	Assuming that other adjacent functions and equipment are operating normally.
		—	In this assessment, any redundancy within the function is disregarded, as the redundancy will be treated separately.
		—	Other mitigating actions shall not be considered at this stage, i.e. spare parts, manning, and tools.
		—	The most serious but nevertheless realistic effects of a function fault shall be identified according to set risk criteria, see 5.4.
6	**Assign MF redundancy**	—	MF redundancy shall be specified, see Table C. 2 for examples of redundancy definitions.
		—	In the case of safety systems or protective functions with redundancy due to functional reliability or regulatory requirements, the redundancy effect should not be accounted for.
7	**Assign SF consequences**	—	The consequence on the system or plant of a fault in an SF is assessed with respect to HSE, production and cost according to the same principles as outlined for MF.
		—	For process systems, the standard sub-function list in Annex B should cover the sub-function consequence. Those standard sub-functions inherit consequence and redundancy from MF based on defined rules. In cases where either consequence or

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Table 1 — Stepwise classification work process *(continued)*

No	Step		Activity
			redundancy deviates from that list, custom sub-functions should be considered. In those cases, consequence and redundancy should be assigned individually.
8	**Assign SF redundancy**	—	If there is redundancy within an SF, the number of parallel units and capacity per unit shall be stipulated, see Table C. 2 for examples of redundancy definitions.
9	**Equipment mapping to function**	—	The equipment (identified by its tag numbers, see Clause 7) carrying out the SFs are assigned to the respective SFs.
		—	If equipment performs more than one SF (e.g. instrument loops), it is assigned to the most critical SF.
		—	All equipment (identified by its tag number) will inherit the same description, consequence classification and redundancy as the SF of which they are a part, see Annex C for an example.
10	**Result per equipment**	—	Consequence analysis shall be documented according to 8.4, and the key data be available in the CMMS.

8.4 Documentation of consequence classification

The assessment should be made available and traceable for updates and improvements of the results as more information and feedback from the operation become available. As a minimum, the following shall be documented:

— decision criteria;

— basis for the assessment;

— assumptions made;

— definition of consequence classes;

— MF description;

— SF description;

— assignment of equipment (tags) to SF;

— assessment of the consequences of loss of MFs and SFs for all consequence categories, including necessary arguments for assignment of consequence classes;

— assessment of MF and SF redundancy;

— completion date;

— any deviations shall be documented and explained.

8.5 Quality check versus technical barriers

Quality check versus technical barriers should be performed when classification and barrier processes have finished their initial phase:

a) consequence classification of main and sub-function, see 8.3, typically managed by the maintenance discipline;

b) technical barrier elements, see 5.2, typically managed by the technical safety discipline.

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The Quality review shall compare all proposed Barrier elements or Barrier Functions, against main and sub-functions from consequence classification. The purpose is to ensure consistency between high HSE classification and the defined barrier functions.

9 Maintenance program

9.1 General

This clause describes how the consequence classification shall be used to establish a risk-based maintenance program.The purpose of a maintenance program is to control or mitigate risks associated with the degradation and malfunction of a function. Maintenance activities include predetermined- and condition-based activities. The program should include maintainable items, activities, intervals, workforces, necessary spare parts and tools per item.

The consequence classification, as described in Clause 8, shall be used as a basis for the selection of the maintenance activities and –intervals.

The maintenance program shall be risk based and mitigate the occurrence and consequence of critical failures.

Using GMC is an efficient and cost-effective way of developing a risk-based maintenance program, see 9.4.

9.2 Work flow for establishing preventive maintenance program

9.2.1 Task selection

The results from the consequence classification, as described in Clause 8, shall be used as input to the preventive maintenance program task selection process. This analysis can typically be a screening for which items to analyse further in more detail.

The task selection process is shown in Figure 4 and described in this sub-clause.

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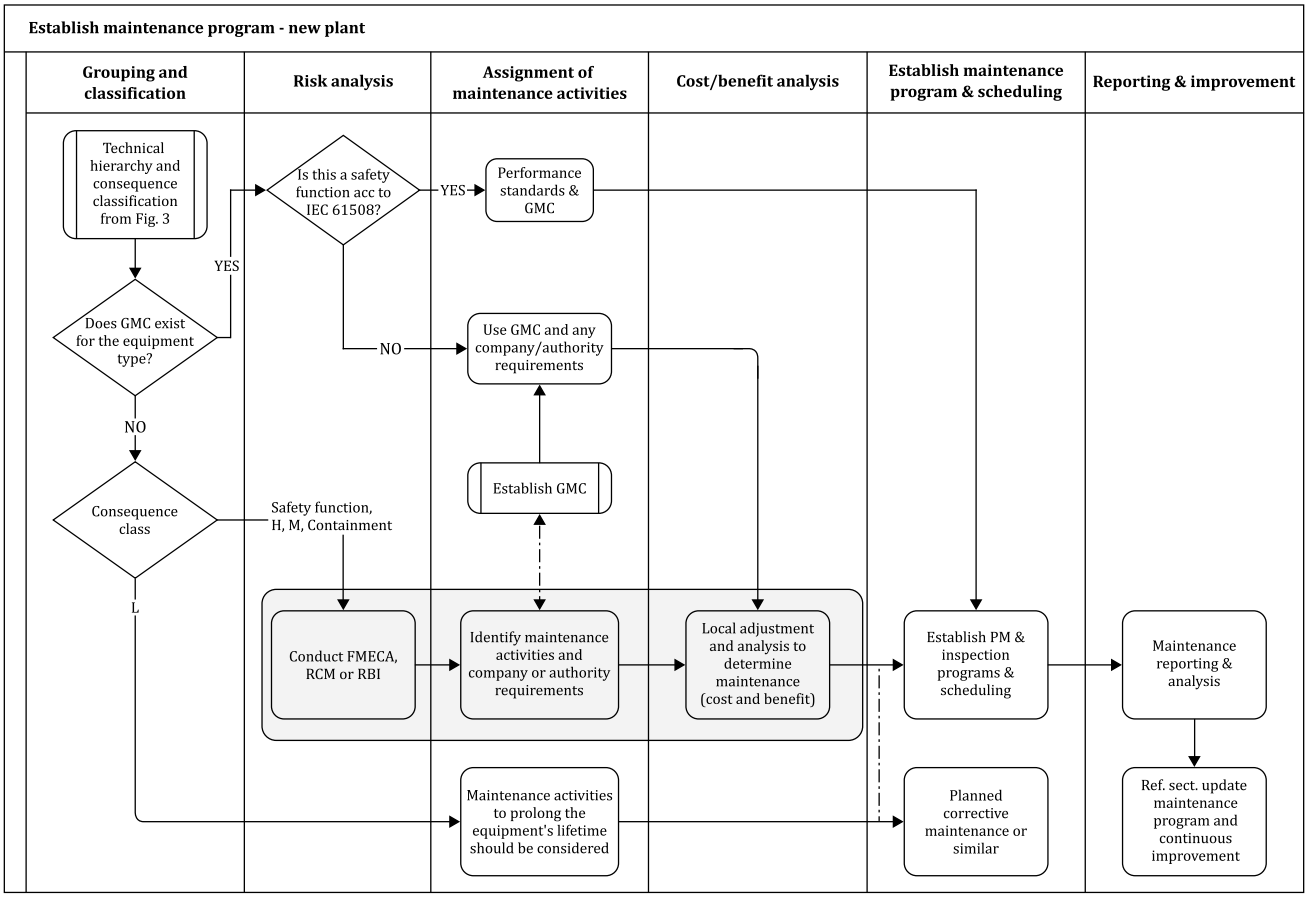


Figure 4 — Establishing maintenance program

For items classified with high consequences of failure on HSE, the items' failure modes shall be identified and analysed with respect to the effect on the item functionality. This should also be done for items classified with high consequences of failure on operation or cost in order to maintain production efficiency and reduce cost.

The recommended approach is to perform a failure mode effect and criticality analysis to identify critical failure modes and the contributing failure mechanisms that need to be controlled or mitigated.

See NEK EN IEC 60812 [23] (or similar standards) for more information on how to perform an FMECA analysis.

Failure modes identified in the failure mode analysis that are critical to the function of the item shall be controlled or mitigated. This should be done using a reliability-centred maintenance approach, where the failure characteristics are analysed to identify the optimal method to control or mitigate the failure mode under development. This can include hidden failures, the possibility of detecting failure, failure patterns, the availability of condition monitoring, etc.

See NEK IEC 60300-3-11 [24] (or similar standards) for more information on how to perform an RCM analysis.

Failure modes that are not critical to the function of an item, as well as items performing functions that do not have a significant effect on safety, external environment, working environment, operation or cost, can be assigned minimum maintenance requirements to prolong the lifetime of the item based on a cost-benefit analysis. This can include operational procedures, cleaning, lubrication, simple verification tests, etc.

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Items with medium or low consequences of functional failure may still have failure modes that render them unsafe in operation and which need to be controlled or mitigated. See 9.2.2 for more information.

If no preventive maintenance or assurance activities are identified to be required or cost-effective, the item or failure mode may be assigned a planned corrective maintenance strategy.

The maintenance task intervals should be based on knowledge and experience from similar items operating under similar conditions and then be adjusted based on equipment's history, risk and cost consideration for specific installation or assets.

For items belonging to the same equipment category or specification with similar failure modes, mechanisms, and operating conditions, GMC can be used to perform the task selection process more efficiently. See 9.4 for more information.

9.2.2 Equipment characteristic unsafe failures

Some items can suffer failure modes that render them not safe in operation but which do not harm the primary function of the item. Example is damage to electrical insulation causing short circuit hazardous for personnel touching the item. The electrical failure is usually not considered a failure mechanism but represents a hazardous situation.

These failure modes or failure mechanisms related to the characteristics of an item shall be identified and assigned probability and consequence, as well as preventive maintenance tasks to control the risk.

This is best identified in a task selection process as described in 9.2.1 and can be documented as part of a GMC (see 9.4).

9.2.3 Maintenance of technical barrier elements

Safety- and environmental barrier functions are usually defined in barrier analysis based on identified major accident hazards. The elements (tags) performing a barrier function need to be identified, and the selection of verification tasks for elements within a barrier function (safety or environment) is based on work processes under barrier management.

9.2.4 Maintenance program

The identified preventive maintenance tasks, including maintenance items, activities, intervals, required resources and materials, etc., shall be implemented in a CMMS.

When establishing the preventive maintenance program, the impact on operation should be considered. This includes minimising unnecessary planned maintenance stoppages, establishing efficient work packages, grouping maintenance tasks for similar maintenance items, planning campaigns, shutdown or turnarounds and daily or weekly rounds of operations personnel, etc.

In developing the maintenance program, local knowledge and experience should be utilised. This includes the working environment, operating conditions, maintenance history, reliability data, workload, maintainability, etc.

The created work orders shall, as a minimum, contain information about priority, start or end date, overdue date, required spare parts and resources, personnel, task duration, shutdown requirements, etc., for proper planning and follow-up of maintenance. See 11.2 for more information.

9.3 Maintenance of technical barrier elements

The performance requirements of the technical barrier element shall be described so that the person performing the verification activities can test, verify and report the condition of the item. This especially applies to technical barrier elements with hidden failures or dangerous undetectable failures which are not normally evident to operation- and maintenance personnel.

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For items with function tests, the maintenance management system shall, as a minimum, contain the following:

— description and requirements of the test (e.g. no maintenance before function test);

— failure characteristics (e.g. valve does not close within the specified time);

— acceptance criteria (e.g. closing time 12 seconds);

— how the function test shall be reported (e.g. “create notification in CMMS with failure mode fail to close”).

A work process shall be in place to analyse test results and verify that the availability of the barriers is in accordance with the design and operational requirements, typically SIL requirements and performance requirements.

9.4 Generic maintenance concept

9.4.1 General

Performing FMECA- and RCM analysis on all items with high consequences individually on an installation can be costly and time-consuming. Using GMC is an efficient and cost-effective way of developing a risk-based maintenance program, standardising maintenance activities and capturing and sharing company experience and knowledge.

A GMC is a set of maintenance actions, strategies and maintenance details which demonstrates a cost-efficient maintenance method for a defined generic group of items functioning under similar frames and operating conditions. The use of the GMC shall ensure that all defined HSE, production, cost and other operating requirements are met. The concept should include relevant design and operating conditions and should be documented by an FMECA or RCM analysis. A generic concept can be seen as a collection of best practices for a company and, as such, should be maintained and updated via a controlled process as new experiences and technology become available, see Annex D.

The GMC shall be established based on the same task selection work process as described in 9.2 for individual items but performed on a generic group of items and include recommended maintenance interval and maximum allowed interval. See Annex D for an example of how to document GMCs.

The extent of documenting maintenance activities and their acceptance criteria will depend on the equipment or system's complexity and associated risks.

GMCs may be developed in order to:

— establish a company’s minimum requirements for maintenance,

— reduce the effort in establishing the maintenance program as similar items and technologies are pre-analysed,

— ensure uniform and consistent maintenance activities,

— facilitate analysis of the group of items,

— provide proper documentation of selected maintenance strategies,

— ensure experience transfer between plants with similar technology and operation, and

— increased level of standardised maintenance for similar types of equipment.

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9.4.2 Application of generic maintenance concepts

GMCs are applicable for most types of equipment on any offshore or onshore installations. A GMC can be utilized when:

— the group of equipment has a similar design,

— the equipment has similar failure modes, failure frequencies and operating conditions,

— the amount of similar equipment justifies the development of a generic concept, and

— there is a need to review the maintenance performance of any equipment, taking GMC as a benchmark.

In case of significant differences between the actual equipment and the equipment which has been the basis for the GMCs, the equipment in question has to be treated individually as a separate generic class of equipment. Basically, equipment failure modes are independent of equipment functionality, i.e. which functions the equipment supports. However, operational conditions, location and external environmental impact may influence the probability of failure and should be assessed prior to use of GMCs.

For complex equipment packages with a high consequence in case of failure, like gas turbines, top drives and offshore cranes, a complete FMECA or RCM should be performed for each individual equipment package in order to capture the complexity of these kinds of items. However, for individual items that are part of the complex item, like valves, transmitters, etc., the general maintenance concepts can be used as input to the analysis of the complex item.

Expected corrective maintenance, required resources, and spare parts can also be added to the GMC and thus make the GMC a tool for benchmarking and input to design and operational and maintainability studies.

9.5 Maintenance program and handling of ageing

Most maintenance programs are based on a relatively constant failure frequency and do not consider the ageing development that systems can suffer. The same principles for continuous improvement, as described in 11.5, can be used. However, the continuous improvement process might not have the same long-term view and take into account simultaneous failures that come into effect when the installation is reaches its intended lifetime.

The cost regarding ageing and displacement or restoration of an item should be taken into consideration in the Life Cycle Cost analysis (see NS ISO 15663 [20]). In the operation phase, a register of risk-ranked vulnerabilities can be made with expected future operating costs and modification or capital cost requirements.See Offshore Norges guideline 122 [25] for required documentation of maintenance and inspection in connection with a formal application for consent of extended lifetime.

10 Maintenance planning

10.1 Maintenance planning and scheduling

A maintenance plan covering both preventive and corrective maintenance shall be available. HSE critical or operation critical maintenance activities shall be included in the installation total activities plan.

The PM program is established as described in Clause 9. This program consists of a list of preventive maintenance activities and intervals for a plant. In order to facilitate proper planning, the preventive maintenance work orders should be generated in the CMMS in due time.

Planning of preventive and corrective work orders should include the necessary preparation for the activity, such as materials, personnel, tools, access, impact on operations, etc.

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10.2 Prioritizing maintenance activities

Criteria for setting the priorities and deadlines for maintenance activities shall be established. Prioritising shall be based on the consequence classification, failure impact, failure development time and mitigating measures.

Prioritising of planned and corrective maintenance activities should be aligned.

Preventive maintenance work orders are based on risk and failure frequencies for the failure mode and should, in principle, be executed according to the given maintenance plan. The backlog related to the plan shall be prioritised based on risk, i.e. probability and consequence of failure.

Prioritisation of corrective maintenance shall be done based on the risk of functional failure.This process can also be named “risk-based work selection” and implemented in maintenance management systems in companies. Figure 5 shows an example of such a workflow, i.e. a selection of which corrective work orders to prioritise.

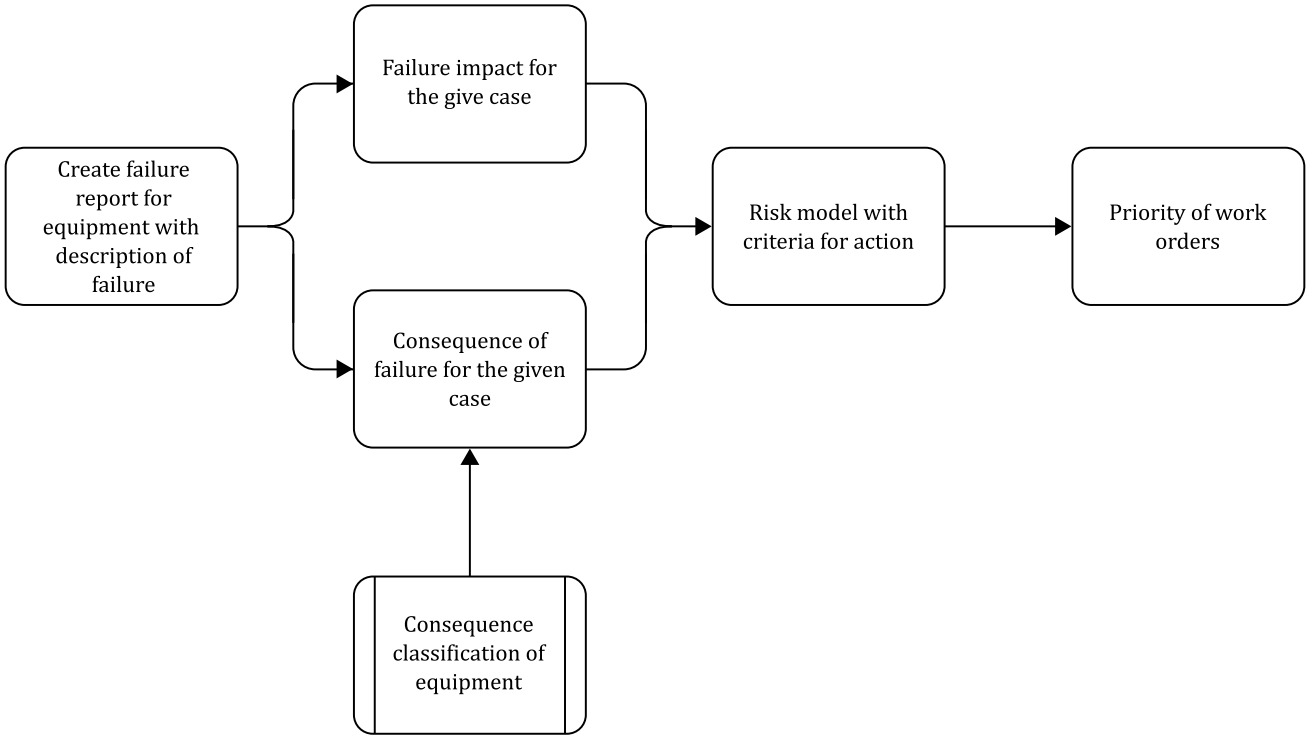


Figure 5 — Priority of corrective work orders

The process involves the following:

— assigning the consequence of failure to the case. It can be assigned via the consequence classification of equipment on an overall functional level. This consequence shall always be based on the actual failure mode.As such, the process cannot be automatic but requires involvement from personnel knowing the plant and the actual case, e.g. unsafe failure modes (see 9.2.2) for low-consequence equipment;

— assigning the failure impact, see Table 2 and Clause 3. A time-to-failure scale may also be used, see Table C.3;

— for failure impact “degraded or incipient failure”, a time to failure shall be assigned and used in the setting of priority (time) for the repair work;

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— the risk associated with the consequence and probabilities, as well as actions from this risk (priorities), shall be defined in the given criteria, e.g. via a risk matrix.

EXAMPLE Table C.3 shows an example of a risk model described as a risk matrix used to determine the priority;

— compensating operational actions used to temporarily maintain the function can be described as redundancy;

— compensating measures shall be in place when failure in the safety-critical functions has occured.

Table 2 — Failure impact scale

Failure impact	Definition	Note
Critical failure	Failure of an equipment unit that causes an immediate cessation of the ability to perform a required function.	Includes failures requiring immediate action towards cessation of performing the function even though the actual operation may continue for a short period of time. A critical failure results in an unscheduled repair.
Degraded failure	Failure that does not cease the fundamental function(s) but compromises one or several functions.	The failure can be gradual, partial or both. The function can be compromised by any combination of reduced, increased or erratic outputs. An immediate repair can normally be delayed, but in time, such failures may develop into a critical failure if corrective actions are not taken.
Incipient failure	Imperfection in the state or condition of an item so that a degraded or critical failure may (or may not) eventually be the expected result if corrective actions are not taken.	
Source:NS-EN ISO 14224:2016		

11 Reporting, analysis and improvements

11.1 General

Reporting and analysis of maintenance performance shall be performed to ensure continuous improvement and fullfilment of requirements.

11.2 Reporting

Table 3 shows relevant failure and maintenance data related to maintenance activities that, as a minimum, should be recorded. See NS-EN ISO 14224:2016 for an overview and further details on requirements and recommendations for reporting of data related to maintenance. The need for reporting will vary between systems and equipment and focus shall be on safety critical and production critical items.

Table 3 — Reporting of failure and maintenance data

Failure data	Maintenance data
Failure date	Maintenance category (PM, CM)
Failure mode	Condition of equipment before and after maintenance
Failure mechanism	Maintenance man-hours for activity
Failure cause	Spare parts used
Failure impact	Start and finish time of activity
Operating condition at failure	Active maintenance time
Detection method	Equipment downtime
Source: NS-EN ISO 14224:2016	

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11.3 Key performance indicators for maintenance management

KPIs shall be defined to support the overall goal and strategy for the operational phase. This will indicate the current status of the maintenance being performed and the effectiveness of the maintenance organisation, and support continuous improvement.

Setting up the right set of KPIs facilitates people to focus and prioritise in the same direction. A combination of reactive (lagging, backwards-looking) KPIs and proactive (leading, forward-looking) KPIs should be selected and maintained.

Examples of some relevant KPIs are shown in Table 4. See NS-EN ISO 14224:2016 Annex E and EN 15341 [26] for examples of relevant KPIs.

Table 4 — Examples KPIs

KPI	Purpose	Comment
Preventive maintenance workload	Indication of amount of preventive maintenance work	
Corrective maintenance workload (NS-EN ISO 14224:2016 Table E.3)	Indication of amount of corrective maintenance work	
PMs overdue (NS-EN ISO 14224:2016 Table E.3)	Indication of outstanding PM backlog	Both number of work orders and man-hours should be recorded
HSE critical PMs overdue	Indication of outstanding HSE critical PM backlog	Both number of work orders and man-hours should be recorded
CMs overdue	Indication of outstanding CM backlog	Both number of work orders and man-hours should be recorded
HSE critical CMs overdue	Indication of outstanding HSE critical CM backlog	Both number of work orders and man-hours should be recorded
Failure fraction (NS-EN ISO 14224:2016 Table E.3)	Average unavailability (PFDavg) due to dangerous undetected failures is established by using test reports	Target failure fraction should be based on risk- and barrier analysis

Key KPIs should be measured continuously where possible. Other KPIs that require more information gathering should be updated at set regular intervals. Targets for KPIs should be set within a timeframe that is achievable and where any corrective actions will have taken effect.

Targets for KPIs related to unavailability of safety-critical equipment shall be based on relevant risk- and barrier analysis.

11.4 Analysis and improvement

Based on reported maintenance data, the effectiveness of maintenance shall be evaluated systematically.

The organisation shall have an established set of key performance indicators to evaluate against – KPIs reflecting the goals and requirements for the operation, see Clause 5. For practical reasons, some trigger levels should be applied above which a more detailed investigation is done aiming at finding the root cause for the failure. The triggers can be related to:

— HSE-related equipment failure;

— unacceptable production loss;

— cost of single failure events in terms of downtime, repair cost, spare cost or personnel cost;

— number of repeated failures over a given time period for key components;

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— hidden failures (exceeding requirements) detected during testing;

— technical condition assessments outside of expectations;

— increased emissions;

— reduced energy efficiency.

Based on the event(s), the root cause(s) should be identified and necessary actions taken to avoid reoccurrence. The problem in question can be either a single discipline or a multidiscipline. The team allocated to the actual case should typically consist of personnel operating the equipment, maintenance engineers and equipment experts.

A comparison of results from the evaluation or investigation against established decision criteria or acceptance criteria can involve adjustment of the maintenance program. The results may also be used for making decisions regarding replacements, modifications, and upgrades of systems from a life cycle management perspective.

Finally, implementation of the actions identified is a key to sustained improvement, as well as measurement of the effect via KPIs and equipment reliability data.

Learning from successes, failures, and events is key to continuous improvement of the performance of a plant and an organisation. Dedicated efforts should be made to implement a proactive and systematic continuous improvement process.

11.5 Update maintenance program and continuous improvement

A continuous improvement process shall be in place in order to enhance safety levels and, at the same time, reduce equipment downtime and OPEX. Reference is made to Clause 5 and Figure 2.

A set of objectives or requirements for the maintenance performance shall be established in order to measure maintenance performance. This shall include acceptance criteria for safety, availability and cost.

It should be possible to extract the necessary technical information from the maintenance management system in order to analyse the effectiveness of the maintenance. This can further be supplemented by input from maintenance and operational personnel.

KPIs and analysis for reporting are described in this clause.

A maintenance program shall be reviewed and updated at regular intervals. The triggers for such updating can be one or more of the following:

— the observed failure frequency or equipment reliability is significantly different from what was expected, i.e.:

  — higher failure frequency is observed requiring a change in maintenance strategy or maintenance frequency – or replacement of the unit;

  — lower failure frequency or no observed damage at PM can point towards extension of intervals or omitting certain tasks.

— the operational environment has changed, causing different consequences and probability of failure:

  — less or more production;

  — change in product composition;

  — change to company strategy.

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— cost of maintenance different from expected:

  — new technology that can make maintenance more efficient (like new methods for condition monitoring) is available;

— updated regulations;

— information from the vendor;

— modifications or replacement with new equipment;

— changes to company's strategy.

A process diagram to update a maintenance program is shown in Figure 6. If there is a significant change in the safety system performance stated in the PS, this information shall be fed back to the overall risk assessment for the plant.

For non-safety systems, a cost-benefit analysis based on experience should be performed. Based on this evaluation, the maintenance program and GMC (if relevant) should be updated and implemented in the maintenance plan.

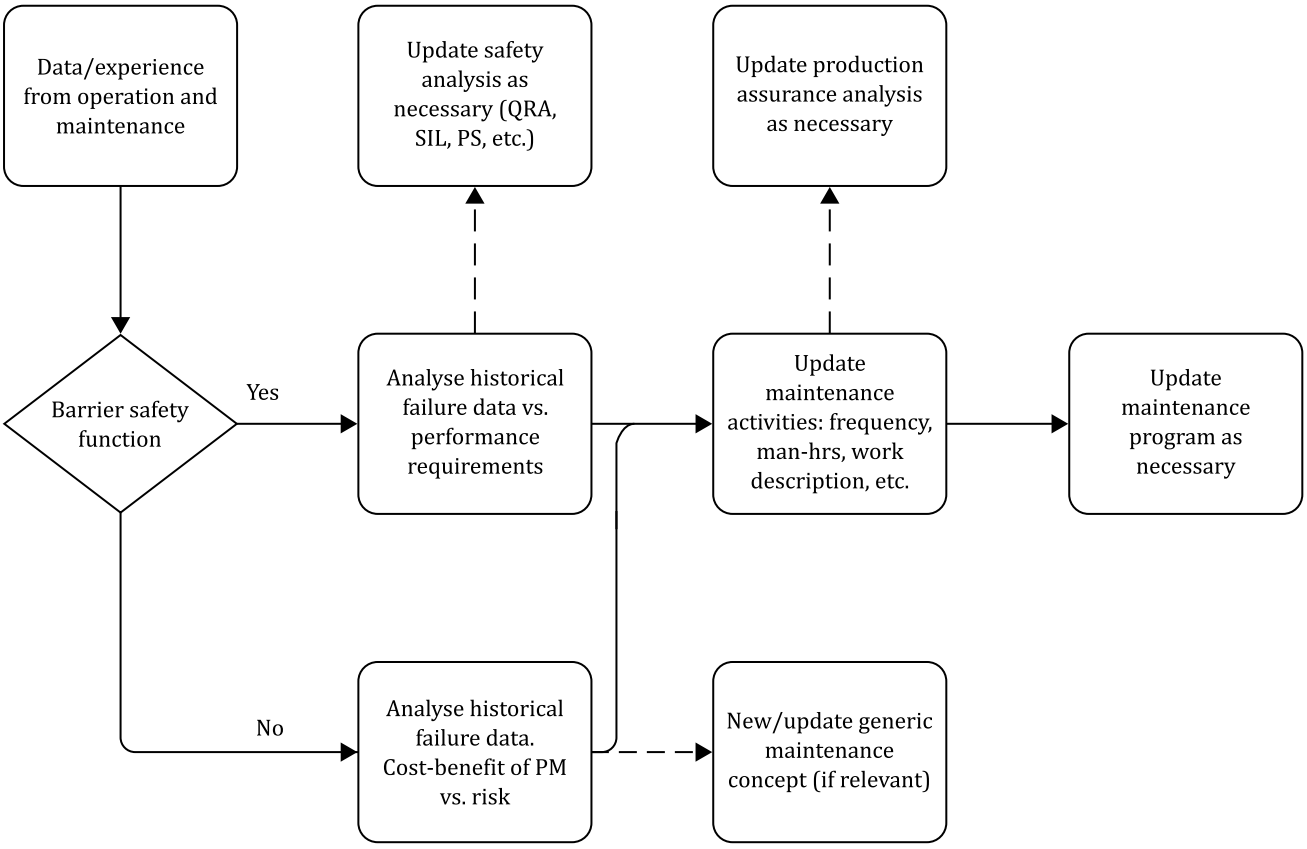


Figure 6 — Process for updating maintenance program

12 Spare parts evaluation

12.1 General

The spare part assessment defining the need for spare parts and the spare part strategy (number of, location and lead time) shall be based on results from the consequence classification (Clause 8) and other relevant analyses like reliability analysis and barrier analysis (see 5.5 for more examples).

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The PM program gives the type and estimate of the demand rate for spare parts used for PM.

The demand rate and which spare parts are needed for corrective maintenance are more challenging to estimate. The typical sources are historical maintenance and inventory transactions, installation-specific data, generic reliability data (e.g. OREDA®), and vendor and maintenance personnel experience.

The maintenance order should state the needed spare parts for the activity.

Further parameters such as procurement lead time and transportation time will have a significant impact on the ultimate quantities of spare parts to be held, their quantities, as well as location.

12.2 Work flow for evaluation of spare parts

Figure 7 gives an overview of the workflow for the evaluation of spare parts. 12.3 to 12.5 details the content in each box.

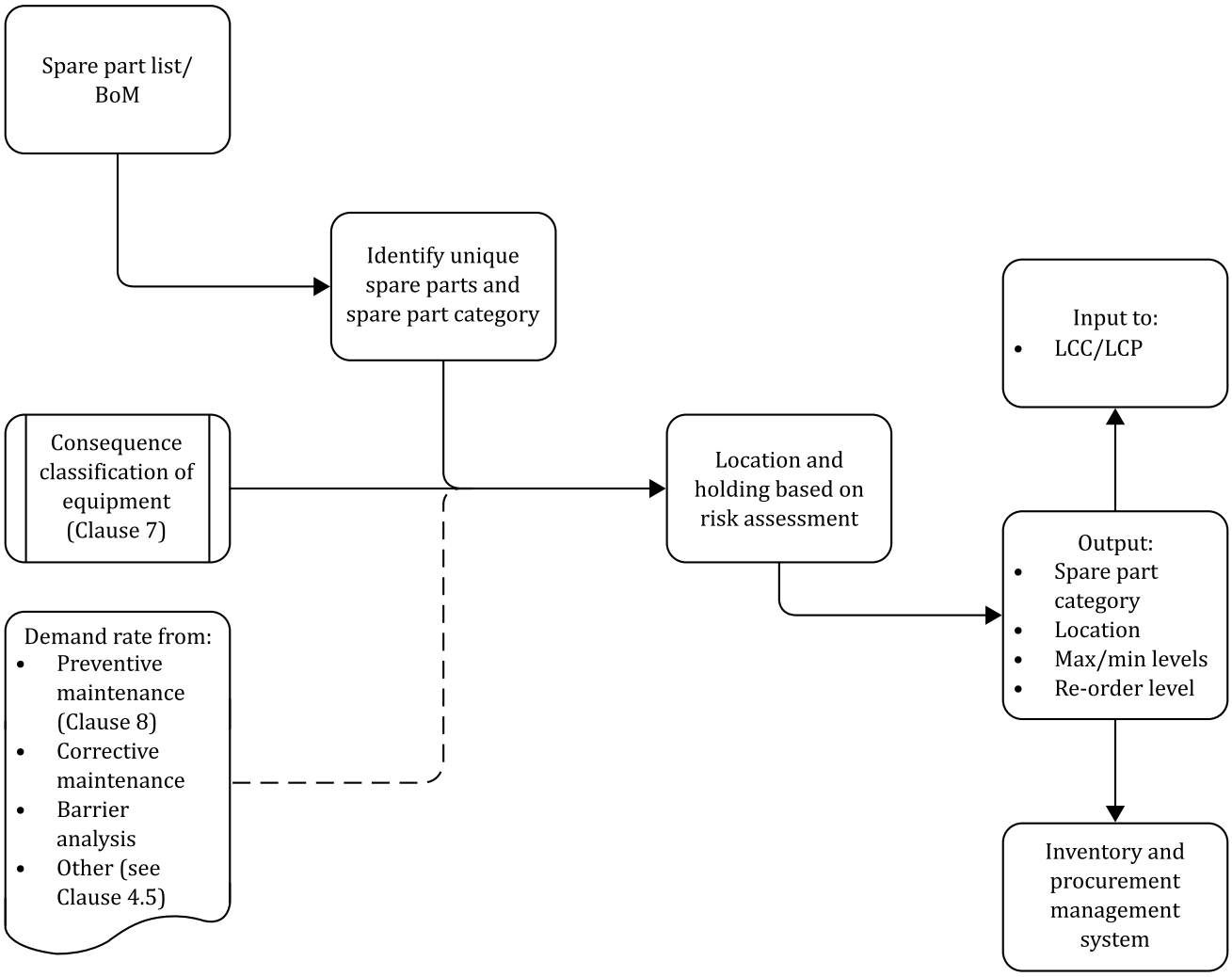


Figure 7 — Evaluation of spare parts

12.3 Spare part categories

Spare parts can be generally categorised as follows:

— capital spare parts:

  — vital to the function of the plant but unlikely to suffer a fault during the lifetime of the equipment;

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  - delivered with unacceptably long lead time from the supplier and usually very expensive;
  - often, these spare parts are characterised by a substantially lower cost if they are included with the initial order of the system package
- operational spare parts:
  - spare parts required to maintain the operational and safety capabilities of the equipment during its normal operational lifetime.
- consumables:
  - item or material that is not item-specific and intended for use only once (non-repairable).
- insurance spare part.
  - spare part which is not normally needed during the useful life of the item but whose unavailability would involve an unacceptable downtime due to its provisioning

Spare parts from different vendors and suppliers should be registered and uniquely identified in the maintenance management system by using the OEM equipment number.

12.4 Location and holding

Spare parts are normally held at various locations. Determining the optimum location for a spare part should be done by use of a risk model where the dimensions are a consequence of not having the spare parts in place and the demand rate. See Annex C for an example of a risk matrix to use in determining location.The demand rate can be estimated from preventive and corrective maintenance.The consequence of not having the spare part in place can be established for this purpose or by use of the functional classification, see Clause 8.

12.5 Reorder level and order quantity

The reorder level and order quantity are important parameters of controlling that spare parts are available without under or overstocking.Traditional inventory methods and formulas can be used to estimate these parameters for operational spare parts and consumables.Capital spare parts are evaluated case by case based on a risk assessment. The output is a level of spare parts which incurs the minimum combination of costs and risks.

The reorder level is based on demand rate and delivery time, adjusted by a safety factor due to uncertainty. Order quantity is estimated based on demand rate, cost per order, and holding cost.

12.6 Additive Manufacturing

Additive manufacturing (AM) is a computer-controlled process that creates three-dimensional objects by depositing materials, usually layer by layer. Due to its capabilities compared to more conventional manufacturing methods, AM may enable the energy and maritime industries to take advantage of new part designs, improved lead times, reduction of waste from manufacturing, and new types of supply chains.

This technology has the potential to reduce the demand for stocking and lead time and thereby reduce costs related to spare parts management.

AM may be considered for both existing assets and new plants as an option in the spare parts selection. Key elements to consider are:

- availability of component data models, either from original drawings or 3D scanning of the parts to be replaced,
- qualification of the manufacturing process and quality of the final product,

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— availability of qualified 3D printing workshops, and

— cost vs traditional spare ordering.

AM can, in principle, be applied to all types of spares listed in 12.3, but suitability may depend on material type, complexity, unit cost, predicted lead time, and predicted demand rate.

DNV ST-B203 [27], API Standard 20S [28] and API Standard 20T [29] gives guidance to the qualification and production of parts using additive manufacturing.

13 Personnel and resources

In order to get quality in maintenance engineering, including consequence classification, program development, acceptance of changes and creating a basis for continuous improvements, it is necessary to involve maintenance personnel and production operators in the risk assessment and preparation of maintenance activities. A dynamic maintenance program requires proper documentation of the evaluations for future adjustments and improvements according to new experiences and changes in operational conditions. This applies irrespective of whether GMCs are applied or a maintenance program has been developed on the basis of the RCM, RBI or SIL analysis.The following type of personnel or experience should be involved:

— maintenance personnel with specific experience from different types of systems or equipment, which typically will involve mechanical, instrument, electrical and corrosion or inspection qualification on the senior level;

— maintenance planners or maintenance supervisors;

— operation and process personnel with process or production experience handling the production impact of a failure;

— personnel with specific experience related to risk assessment and maintenance analysis – often acting as facilitators driving the process;

— maintenance engineers.

The above personnel may be employed by the operating organisation, vendors or consultants.

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Annex A
(informative)

Main function (MF) description and boundaries

Descriptions of MFs should aim to describe an active function (i.e. 'Pumping' instead of 'Pump') while still contextualizing the equipment.Descriptions commonly used for MFs are shown in Table A.1. Normally, a further specification is required to describe the MF sufficiently.If relevant, the availability, capacity and performance should be specified.

Table A.1 — Examples of MF descriptions

MF description	Sub title, examples
Accumulation	Instrument or plant air, heating or cooling medium
Cementing	
Circulating	Heating or cooling medium
Compressing	Gas export or injection
Cooling	
Detecting	Fire and gas
Distributing	(Main or emergency) power, hydraulic, tele
Drying	Air, gas
Emergency lighting	
Escape lighting	
Expanding	
Filling	Lubrication oil
Filtering	
Fire fighting	Sprinkler, deluge, water spray, foam, gaseous fire systems, hydrants
Generating	(Main or emergency) power
Heating	
Injecting	Chemicals, gas, water
Life Saving	Mob, lifeboat, basket, raft, escape chute
Lifting	Deck crane, personnel, goods
Lighting	
Logging	Well, production, mud
Manoeuvring	
Metering	Fiscal (gas or oil), CO_2
Producing	
Pumping	Oil or gas export, bilge, seawater
Regenerating	Glycol
Scrubbing	Gas
Separating	Production, test, cyclone- (water, sand or oil), centrifuge
Storing	Oil, gas, chemicals, potable water, lubrication or seal oil
Transferring	Oil or gas pipe (riser), power
Transforming	Electrical transformer

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Examples displaying the MF HF2020 (along with others) with boundaries marked on a flow diagram and the same MF with boundaries marked on the more detailed P&ID are shown in Table A.1 and Figure A.2.

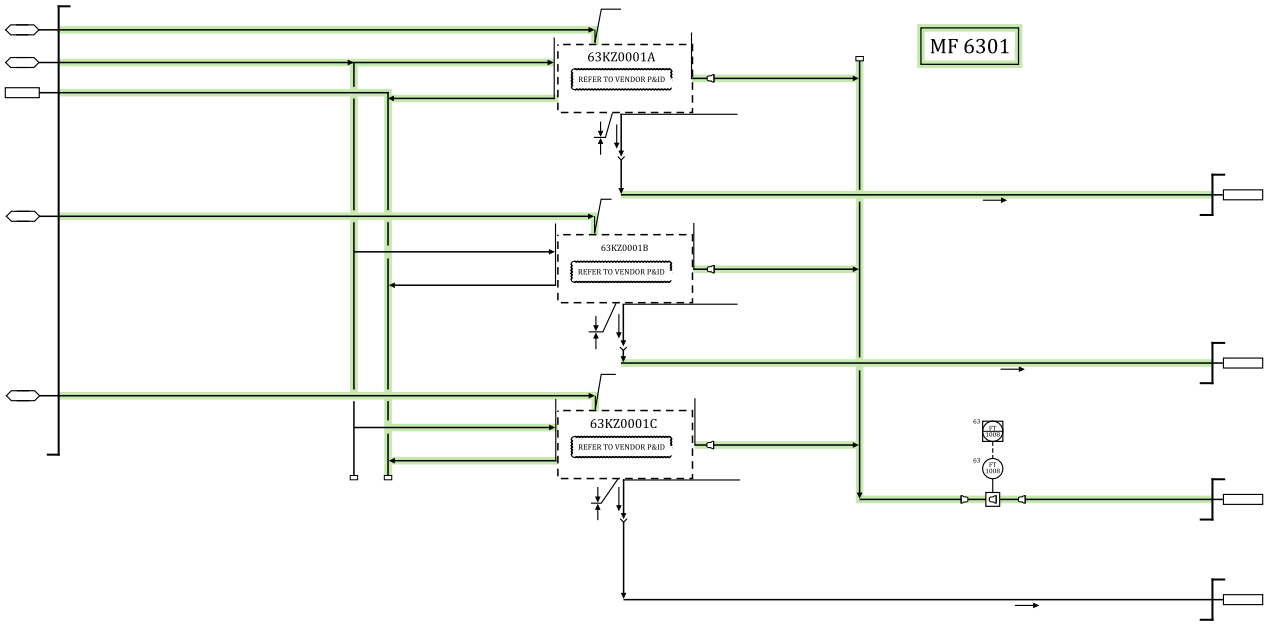


Figure A.1 — Flow diagram showing borderlines for MF 6301

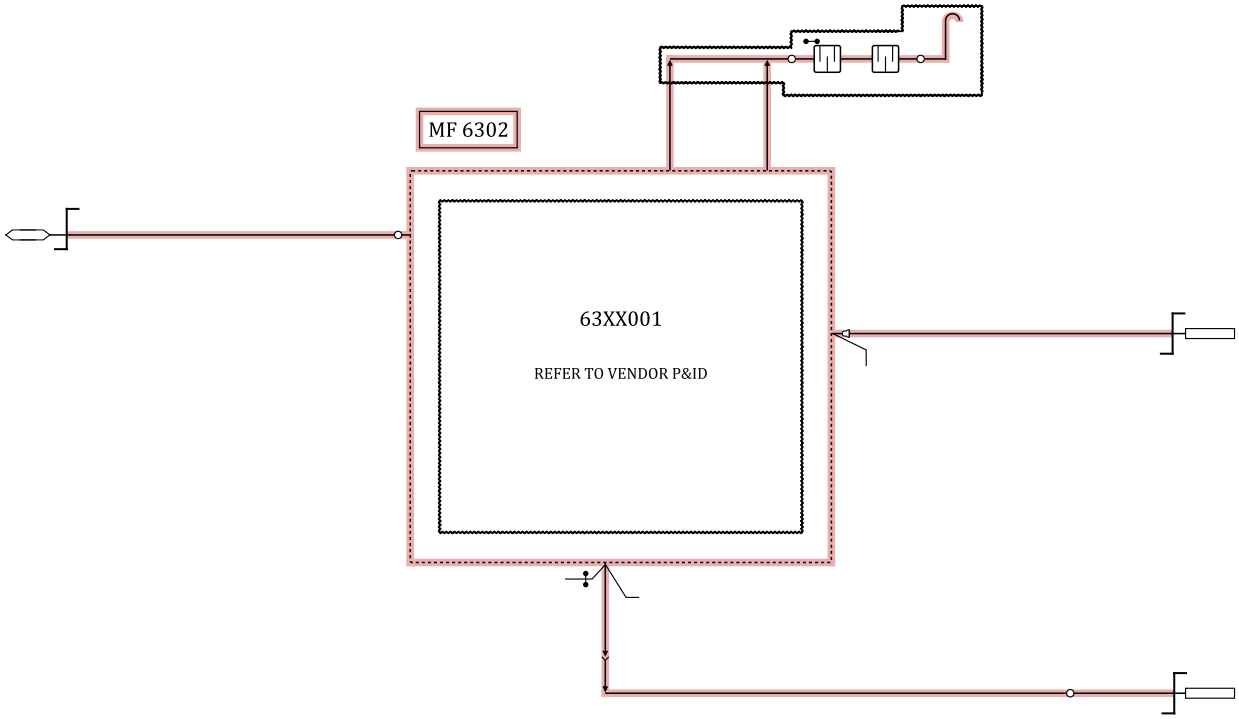


Figure A.2 — P&ID showing borderlines for MF 6302

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Annex B
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Simplifying consequence assessment of standard sub functions

The consequence assessment of the MF already performed should be used as a basis for establishing the consequence assessment for the standard SFs. It is recommended that these evaluations are verified by experienced process personnel and adjusted individually. Custom sub-functions should be created if needed.

An example of the standard SFs is shown in Table B.1.

NOTE Custom sub-functions have to be assessed independently for both loss of function consequence and redundancy.

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Table B.1 — An example of consequence assessment of standardized SFs, based on the MF consequence assessment

Standard SF	Classification of loss of function				Comment
	RED	HSE	PROD	Other	
Main function	MF	MF	MF	MF	
Pressure, relief	Configuration	H	L	L	Note 1 Note 2
Shut down, process (ESD/PSD)	A	H	L	L	Note 1 Note 3
Shut down, equipment	MF	M	L	MF	Note 4 Note 5
Controlling	MF	MF	MF	MF	Note 6
Monitoring	MF	M	L	L	Note 7
Local indication	MF	L	L	L	Note 8
Manual shutoff	MF	(MF)	(MF)	(MF)	Note 9

Table Key:

HSE, PROD, Other	See examples and definitions in Annex C
H, M, L	Consequence “High”, “Medium” or “Low”
MF	Will inherit MFs
RED	Redundancy, see definition in Table C. 2.
(MF)	Reduce with one level from MF
Note 1	No redundancy for the failure mode 'Fail to operate on demand'
Note 2	Pressure relief valves installed for preventing overpressure or vacuum in pressurised systems. Safety critical pressure relief is often related to hydrocarbon-, high-pressure systems and relief to flare. For other applications, custom sub-function may be considered.
Note 3	Typically valid for equipment in conjunction with PSD or ESD
Note 4	**Other:** Inherits the highest consequence from the MF.
Note 5	Typically valid for equipment related to shut down to prevent breakdown
Note 6	Only valid for equipment regulating the main function
Note 7	Typically equipment for monitoring the main function giving alarms in CCR or local control rooms
Note 8	Typically equipment for in field readings by operator
Note 9	Typically equipment for manual isolation for maintenance

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Annex C
(informative)

Risk assessment criteria

C.1 Risk assessment using risk matrix

An example of a consequence classification matrix is shown in Table C. 1.The classification matrix used for maintenance purposes should be harmonized with the corporate risk matrix.For maintenance purposes, it is usually sufficient to have 3-5 consequence classes, whereas a corporate risk matrix can have many more consequence classes.The different consequence categories should also be the same as used in the corporate risk matrix.The consequence classes should be aligned so the highest consequence is used for planning and prioritization.

Table C. 1 — Example of consequence classification matrix

Consequence category	C1	C2	C3
Safety and health	No potential for injuries. No effect on safety systems.	Potential for injuries requiring medical treatment. Limited effect on safety systems.	Single or multiple fatalities or serious personnel injuries. Render safety critical systems inoperable.
Environment	No or minor spill or emissions	Medium discharge or emissions	Major discharge or emissions
Production	No production loss	Delayed effect on production (no effect in x days) or reduced production	Downtime or loss of production DT > X days
Other	No operational issue (work environment, reputation, etc.) or asset cost consequences (Cost < X USD)	Moderate operational impact (work environment, reputation, etc.) or asset cost consequences (X < Cost < Y USD)	Significant operational impact (work environment, reputation, etc.) or asset cost consequences (Cost >Y USD)
NS-EN ISO 14224:2016 gives another example of failure consequence classification.			

Table C. 2 — Example of redundancy definitions

RED	Redundancy degree definition
A	No redundancy, i.e. the entire system is required to avoid any loss of function.
B	One parallel unit can suffer a fault without influencing the function.
C	Two or more parallel units can suffer a fault at the same time without influencing the function

C.2 Decisions based on consequence classification

As described in Clause 8, the consequence classification is used to plan activities and prioritize resources.

The consequence classification should be used to decide the priority of a corrective work order, together with the failure mode and state of degradation. There should be a matrix in place to set the due date for each corrective work order based on the mentioned criteria. The due date can be changed to a later date than the default date due to lack of spare parts, access, personnel, etc., but the priority of the work order should remain the same. To get hold of the required spare parts and resources should then also be of the same priority.

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If the due date is not met, this should be flagged and, in case of work orders for high consequence items, be classified as a non-conformity and subject to proper follow-up and risk assessment.

Table C.3 gives an example of due dates for corrective maintenance tasks based on the consequence classification.

Table C.3 — Example of priority or time to repair based on classification

Consequence	Priority or time to repair	Comments
High	5 days	Barrier equipment < 2 days
Medium	30 days	
Low	180 days	
Un-Prioritized	360 days	Unclassified

Redundancy should also be taken into consideration when setting a due date and prioritising work.

C.3 Spare parts

An example of consequence classes which can be used to determine the optimum location for spare parts is given in Table C.4. Input from the consequence classification can be used or modified for this purpose. The consequence classes combined with the demand rate give the location of spare parts, as shown in Table C.5.

Table C.4 — Example of consequence classes for spare parts

Consequence	Description
High	Equipment of a system that shall operate in order to maintain operational capability in terms of safety, environment and production.
Medium	Equipment of a system that has installed redundancy, of which either the system or its installed spare must operate in order to maintain operational capability in terms of safety, environment and production.
Low	No consequence for safety, production or the environment.

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Table C.5 — Example of risk matrix for spare parts

Consequence Demand rate	Low	Medium	High
First line spare parts, frequently used.	Minimum stock at site	Minimum stock at site and any additional spare parts at central warehouse	Adequate stock at site
Not frequently used.	No stock	Central warehouse, no stock at site	Central warehouse and minimum stock at site if convenient
Capital spare parts. Seldom or never used.	No stock	No stock	Holding optimised by use of risk assessment case by case

C.4 Risk matrix

The consequence classification gives, as the term implies, the consequence in the case of loss of function. As part of performing an FMECA and RCM analysis, the probability of each failure mode is defined. The probability gives an indication of the uncertainty of when the failure mode is expected to occur.

The consequence of failure and the expected failure frequency from the FMECA analysis can be combined to establish the risk for the failure modes for each item's failure mode, and the overall risk for each item.

From the FMECA or RCM analysis the probability of the failure mode and failure mechanism is defined. If defined as part of a GMC, when assigned to an item the total risk for the particular failure mode for the particular item is defined.

The risk is used as a basis for the maintenance interval for the defined failure mode, see Clause D.3 for an example.

When one GMC is applied to two different items with different consequence classifications or redundancies, the suggested maintenance activities and intervals can be different.

EXAMPLE I.e. items with higher consequence classification will normally have more maintenance and at shorter intervals.

For failure modes that do not affect the function of the item, like EX-protection, the maintenance should be the same regardless of the functional consequence classification. See Clause D.4 for an example of a GMC.

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The expected failure frequency for each equipment and each failure mode can be calculated based on installation- or companywide maintenance records or using generic failure data from OREDA© or similar sources.

However, for practical purposes, it is often better to use qualitative data and expert judgements to set an expected failure frequency, like 2-5 years, 5-10 years, etc., especially for new installations or items where there is little data available to establish a quantitative failure frequency.

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Annex D
(informative)

Practical examples

D.1 Technical hierarchy

The level of detail with regard to tagging is, in many ways, a deciding factor in ensuring that the equipment will receive adequate maintenance. On the Norwegian Continental Shelf, there is an existing practice, in line with local regulations of tagging to a detailed level where even instrumentation and equipment in support of MFs and SFs are tagged. The tagging is to be consistent with drawings, marked on the actual equipment on the installation and the CMMS and is an important part of documenting the equipment through its life cycle.

Figure D.1 illustrates the workflow to establish a technical hierarchy.

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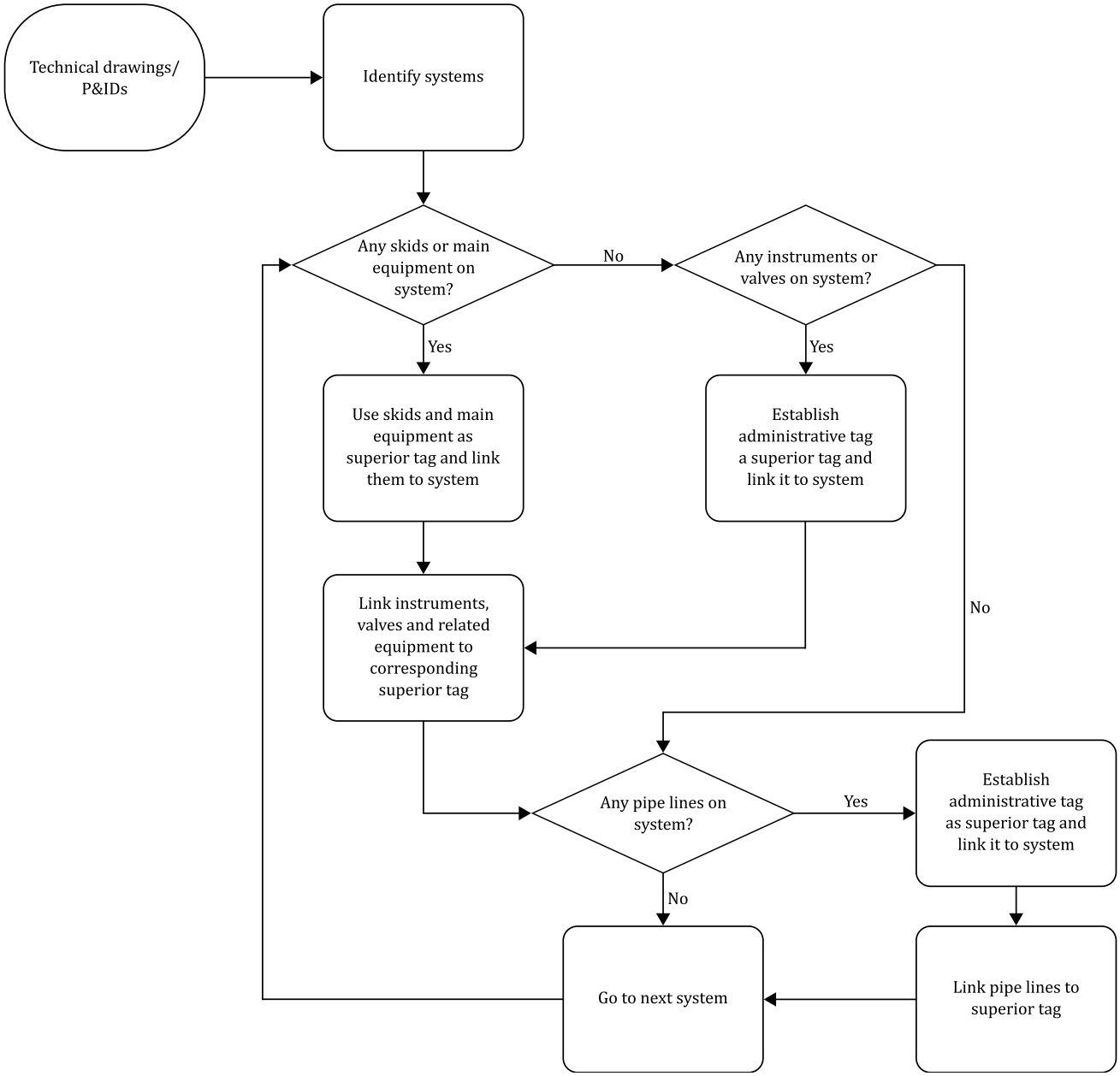


Figure D.1 — Work process technical hierarchy

To establish a technical hierarchy, it is necessary with a set of technical drawings, e.g. flow and single-line diagrams, P&IDs, etc., and a list of tags and a tool for linking tags to each other.

The top of the technical hierarchy normally starts with the installation code with the system numbers listed in Figure D.2.Technical drawings can be used to identify skids, packages and main equipment that can work as a superior tag for the connected instruments, valves and other kinds of equipment.There can be several levels beneath a level, e.g. a skid that contains 2 pumps with electric motors.The skid will then be the top level, the pumps will be the 2nd level, and the electric motors will be the 3rd level to the corresponding pump. Each level can hold corresponding instruments and valves. See Figure D.2.

Start with a system by identifying skids and main equipment. Then, link all the skids and main equipment that will be used as a superior tag to the system number in the tree structure. The next step is to identify the instruments, valves and other kinds of equipment on the system and connect them to the corresponding skid or main equipment. If there are no skids or main equipment, but only, e.g., instruments or valves, then administrative tags should be established to form the level above. Administrative tag it's not a physical

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function location. Administrative tag can be used to obtain a more logical and orderly arranged technical hierarchy.The instruments, valves and other kinds of equipment are then linked to the administrative tag.In instrument loops, one of the components can represent the whole loop, e.g. a transmitter or valve, while the rest of the loop lies beneath.

D.2 Functional hierarchy

The functional hierarchy is a logical diagram linking all the plant functions noted as MF and SFs, see Annex A.The level of detailing of the functional hierarchy may vary, but usually, 2 to 3 levels are sufficient.

Plant system 27 (gas export) is shown in Figure D.3 in a schematic diagram of a plant (platform), which has been broken down into equipment identified by its tag number. The defined MFs covering part of this system and the standardised SFs for one of these MFs are illustrated as an example.

Each tag within one SF is given the same classification because a fault on any of these units (identified by the tag numbers) will cause the same consequence on the MF.

D.3 Documentation of consequence analysis

A typical example of a consequence analysis of an MF (2701 Scrubbing), with standard sub-functions listed, is shown in Table Figure D.4. This MF consists of two parallel units, each able to perform 100 % of the scrubbing function in the relevant operating mode. Although this example identifies 100 % redundancy for this MF, redundancy is ignored at this time.For the purpose of determining the consequence class, all MFs should be considered as single, irrespective of their design redundancy.The consequence classification is 3 (high), 2 (medium) and 1 (low). The degree of redundancy is set by characters A, B or C for the relevant operating mode. The degree of redundancy for sub-functions is set based on the number of parallel units (PU) and capacity (Cap: 50 %, 100 %).

Failure mode	System effect:	Installation effect:	S	P	O
Does not work	Not able to remove liquids from gas. Gas export system shuts down/is not available.	Gas production is shut down. Oil production to be maintained according to tariff quotas. CO_2 and environmental consequences.	1	3	1

Function	**Description**	**PU*Cap -> Red**	**Classification (S,P,O-> Max)**
2701 MAIN	Scrubbing	2*100 -> B	1,3,1 -> 3
2701 ALARM	Monitoring	2*100 -> B	2,1,1 -> 2
2701 CONTROL	Controlling	2*100 -> B	1,3,1 -> 3
2701 IND	Local indication	2*100 -> B	1,1,1 -> 1
2701 PSD	Shutdown, Process	1*100 -> A	3,1,1 -> 3
2701 EQSD	Shutdown, Equipment	2*100 -> B	2,1,3 -> 3
2701 PSV	Pressure relief	1*100 -> A	3,1,1 -> 3
2701 VALVE	Manual shut-off	2*100 -> B	1,2,1 -> 2
2701 PV	Containment, Process Vapour	2*100 -> B	1,3,1 -> 3

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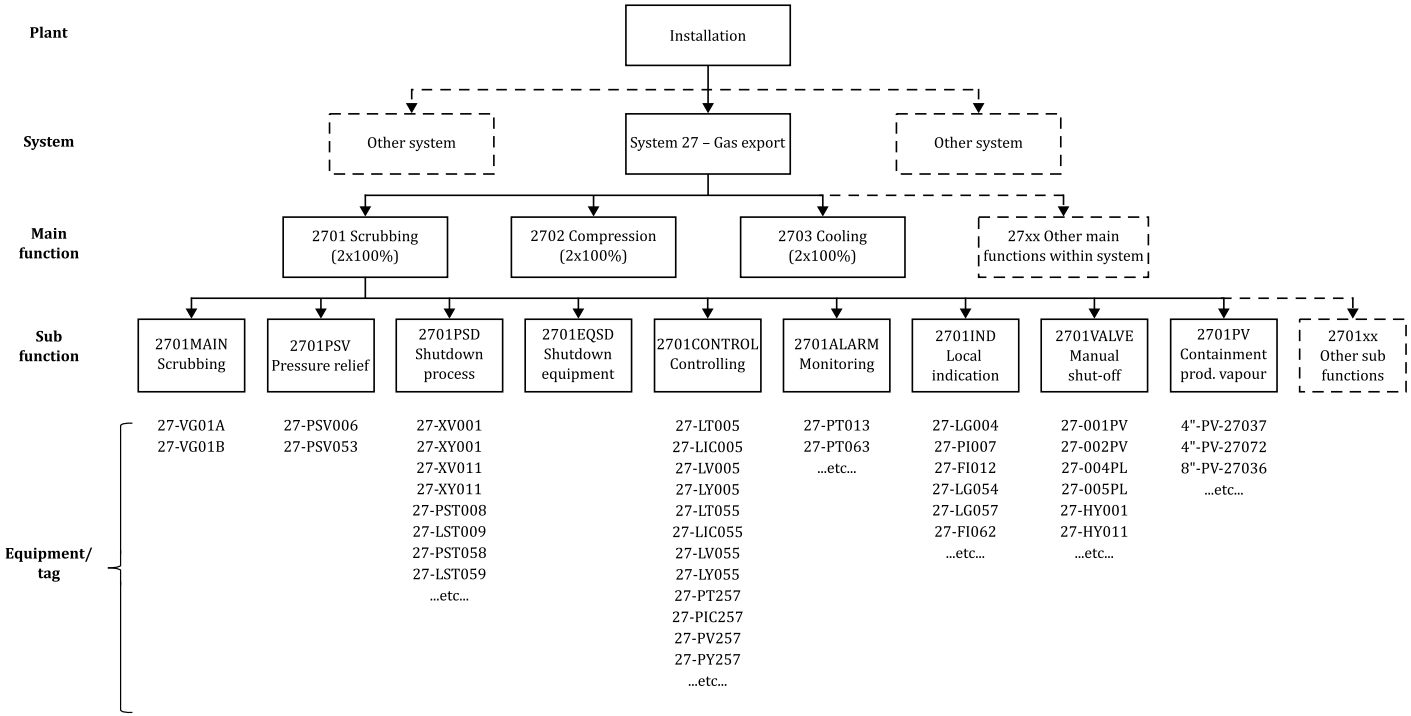


Figure D.3 — Functional hierarchy, example with standard sub function and classification

Table Figure D.4 — Consequence assessment of a MF. The example is shown with some key data and the classification of the sub functions listed below

Z-008	CONSEQUENCE OF MAIN FUNCTIONS AND ITS FUNCTIONS				
System 27: GAS EXPORT AND METERING					
Main Function: 2701	SCRUBBING		Parallel Units: 2	Capacity per unit: 100%	Redundant grade: B
Documents	PID: P&ID 01-01	PFD: PFD 01-01		Rev: B	Last updated: dd.mm.yy
Failure mode	System effect:	Installation effect:	S	P	O
Does not work	Not able to remove liquids from gas. Gas export system shuts down/is not available.	Gas production is shut down. Oil production to be maintained according to tariff quotas. CO_2 and environmental consequences.	1	3	1
Function	**Description**	**PU*Cap -> Red**	**Classification** **(S,P,O-> Max)**		
2701 MAIN	Scrubbing	2*100 -> B	1,3,1 -> 3		
2701 ALARM	Monitoring	2*100 -> B	2,1,1 -> 2		
2701 CONTROL	Controlling	2*100 -> B	1,3,1 -> 3		
2701 IND	Local indication	2*100 -> B	1,1,1 -> 1		
2701 PSD	Shutdown, Process	1*100 -> A	3,1,1 -> 3		
2701 EQSD	Shutdown, Equipment	2*100 -> B	2,1,3 -> 3		
2701 PSV	Pressure relief	1*100 -> A	3,1,1 -> 3		
2701 VALVE	Manual shut-off	2*100 -> B	1,2,1 -> 2		
2701 PV	Containment, Process Vapour	2*100 -> B	1,3,1 -> 3		
Table key Classification (S: Safety; P: Production; O: Other): 3: High 2: Medium 1: Low					

D.4 Documentation of generic maintenance concept (GMC)

A GMC is a set of actions, strategies and details that can be seen as a collection of best practices for a company.The GMC should be defined by a structured RCM analysis where failure modes and failure mechanisms are identified.

All tags should be linked to a relevant GMC and should be available for reference directly in the CMMS.The use of dummy concepts should be restricted to a minimum and only linked to tags where a detailed generic maintenance analysis has revealed no need for any maintenance activity.Equipment which is part of an instrument loop but where no concept is applicable should be linked to the same concept as the superior tag, i.e. the instrumented valve.

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Each concept should specify which type of equipment the concept is covering and which type of equipment is excluded.Each concept should be detailed at such a level that it provides sufficient information, as keywords or by a short description, about relevant maintenance activities and intervals of such activities in order to maintain the equipment's intended function.It should be avoided to specify maintenance activity at the concept which is not relevant to the actual functional location to which the concept is linked.

The following table shows the final result and not the documentation of the entire process.

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Table D.1 — Generic maintenance concept

Equipment class:	El. Motor < 300 kW
Concept note:	Applies for electrical motors independently of voltage and design
Responsible discipline:	E-Electrical
Approved by:	nn
Approved date:	dd.mm.yy

Legend:

D) Discipline	Craft/competence (e.g. MECH: mechanic, ELEC: electric, OPER: operator)
M) Requirement from government/company	Regulations and company requirements. For barrier functions: - Safety critical failure with connected testing interval - SIL requirement (acceptance level)
S) Shutdown	Shutdown required to undertake repair, and possibly production shutdown depending on redundancy and HSE requirements
Equipment class NS-EN ISO 14224:2016	NS-EN ISO 14224:2016 provides a recommended structure for equipment class
Operating and frame conditions	Physical operating and frame conditions for the concept
Responsible	Responsible person/discipline for this concept
Revision	Revision number
Consequence class	Consequence class for maintainable item from consequence classification
Activity description	Description of PM activities
Ref to main doc	Reference to detailed description of maintenance activity
Maintenance Interval	Generic maintenance interval established based on consequence classification, operating conditions etc.
Interval unit	Months, years, hours, etc.

Object	**Activity No.**	**Activity group**	**Activity description**	**D**	**M**	**S**	**Unit**	**Maintenance Interval pr. Consequence class**			**Duration**	**Work load**	
								High	Medium	Low		Resource x time	Total man hours
Motor	66030-51A	51 Lubrication	Lubrication of el.motor	MECH	N	N	M	3	6	-	0,5	MECH x 0,5	0,5
Motor	66030-02A	02 Near	For outside	ELEC	N	N	M	12	12	12	1,5	ELEC x 1,5	1,5

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Table D.1 — Generic maintenance concept *(continued)*

		visual check	motors, check external and internal condition of junction boxes. If the JB has flame slits, check and lubricate.										
Motor	66030-15A	15 Measurement	Megger test stator and rotor windings	ELEC	N	Y	M	12	12	12	0,5	MECH x 0,5	0,5
Motor	66030-71A	71 Overhaul	Overhaul of electrical motor	ELEC	N	Y	H	24000	48000	-	20	2 x ELEC x 20	40

Legend:

D) Discipline	Craft/competence (e.g. MECH: mechanic, ELEC: electric, OPER: operator)
M) Requirement from government/company	Regulations and company requirements. For barrier functions: - Safety critical failure with connected testing interval - SIL requirement (acceptance level)
S) Shutdown	Shutdown required to undertake repair, and possibly production shutdown depending on redundancy and HSE requirements
Equipment class	NS-EN ISO 14224:2016 provides a recommended structure for equipment class
Operating and frame conditions	Physical operating and frame conditions for the concept
Responsible	Responsible person/discipline for this concept
Revision	Revision number
Consequence class	Consequence class for maintainable item from consequence classification

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Table D.1 — Generic maintenance concept *(continued)*

Activity description	Description of PM activities
Ref to main doc	Reference to detailed description of maintenance activity
Maintenance Interval	Generic maintenance interval established based on consequence classification, operating conditions etc.
Interval unit	Months, years, hours, etc.

Failure mode analysis:

Preventive Activity(s)	**Failure Mode**	**Failure Mechanism**	**Failure Cause**	**Frequency (yrs/ failure)**	**Analysis Reference**	**Local Effect**	**Hidden Failure**
66030-02A, 66030-71A	SPO - Spurious operation	Wear	Wear	5-10 Years	Project	Loss of function	Y
66030-15A	FTS - Failure to start on demand	General electrical failure	Protection trip due to overcurrent, overload & short circuit	5-10 Years	OREDA	Loss of function	N
66030-15A, 66030-71A	LOO - Low output	General electrical failure	Voltage unbalance	> 20 Years	OREDA	Degraded Function	N
66030-51A	ELU - External Leakage	Vibration	Bearing friction, lubrication	5-10 Years	OREDA	Degraded Function	N
66030-51A	STD - Structural deficiency	Vibration	Winding failure	5-10 Years	OREDA	Degraded Function	N
66030-51A	VIB - Vibration	Vibration	Bearing fracture/fault		Project	Degraded Function	N
66030-02A	OHE - Overheating	General material failure	Bearing fracture/fault	5-10 Years	Project	Unsafe failure	Y
66030-02A, 66030-71A	FRO - Failure to rotate	General material failure	Mechanical damage	5-10 Years	Project	Loss of function	Y

Legend:

D) Discipline	Craft/competence (e.g. MECH: mechanic, ELEC: electric, OPER: operator)

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Table D.1 — Generic maintenance concept *(continued)*

M) Requirement from government/company	Regulations and company requirements. For barrier functions: - Safety critical failure with connected testing interval - SIL requirement (acceptance level)
S) Shutdown	Shutdown required to undertake repair, and possibly production shutdown depending on redundancy and HSE requirements
Equipment class	NS-EN ISO 14224:2016 provides a recommended structure for equipment class
Operating and frame conditions	Physical operating and frame conditions for the concept
Responsible	Responsible person/discipline for this concept
Revision	Revision number
Consequence class	Consequence class for maintainable item from consequence classification
Activity description	Description of PM activities
Ref to main doc	Reference to detailed description of maintenance activity
Maintenance Interval	Generic maintenance interval established based on consequence classification, operating conditions etc.
Interval unit	Months, years, hours, etc.

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Annex E
(informative)

Addressing climate change (SN-ISO GUIDE 84:2020 [30](E))

ISO Guide 84 expresses two ways to respond to climate change:

— reduce greenhouse gas emissions to remain below the 2 °C above pre-industrial levels and pursue efforts to limit the temperature increase to 1,5 °C above pre-industrial levels;

— increase the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development.

Maintenance management in the context of this standard has a negligible potential to address or respond to the second of these two and a more pronounced potential to address or respond to the former.

This potential lies primarily within addressing climate change mitigation when dealing with GHG emissions from the process industries. Maintenance management may realize this potential through two different categories of efforts:

— take greenhouse gas emissions into consideration when determining the consequences of loss of the containment function and establish preventive maintenance to reflect this;

— use principles as laid out in clauses 5.4 Risk decision criteria, Clause 6 Maintenance management, Clause 11 Reporting, analysis and improvement and Clause 12 Spare part evaluation.

Elaboration on the first category of efforts:

Consequence classification takes into consideration the consequences of leakages with respect to environmental damage from process systems with containment function 5.3 . Following the requirements and guidance in this section may reduce leakages, both in terms of frequencies and leaked volume, from the asset during its lifetime.

Elaboration on the second category of efforts:

None

Elaboration on 5.4 Risk decision criteria and Clause 6 Maintenance management:

Companies which operate within the target of this standard may have set targets to reduce greenhouse gas emissions from their production, which may be reflected in their overall company risk matrices. If this is the case, the consequence- and risk matrices used for maintenance purposes can be aligned with these targets. This may have a significant trickle-down effect on several of the sub-processes of the maintenance management process.

Elaboration on 10 Reporting, analysis and improvement:

KPI for maintenance management reflecting unintended release of gaseous hydrocarbons from equipment may be set up and measured to trigger more detailed investigations to find the root cause for the failure.

Elaboration on Clause 12 Spare part evaluation:

The criteria for selecting spare parts may include criteria which reflect their inherent CFP (carbon footprint of a product), their longevity, their shelf-life, their impact on equipment performance, their impact on equipment life cycle, etc. Applying these types of criteria in the selection of spare parts may lower the overall release of greenhouse gas emissions of the asset.

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