NORSOK Standard

Z-008:2017

Language: English

Risk based maintenance and consequence classification

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Contents

Foreword

NORSOK Z-008:2017 was adopted as NORSOK Standard in December 2017.

NORSOK Z-008:2017 supersedes NORSOK Z-008:2011.

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; and
- 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 N:2016 directive.

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

This NORSOK directive has been developed by Standards Norway in cooperation with the parties in the petroleum industry.

All sections are normative. All Annexes are informative.

The following has been changed since last edition (revision 3, June 2011):

- Changed scope to include all types of equipment in all types of installations
- Updated references and terminology. ISO14224:2016 is used as the basis for maintenance terminology
- Added section regarding input to consequence classification and maintenance engineering
- Description of maintenance engineering of technical barrier elements
- Better general description of work process for establish preventive maintenance programme
- Review of standard to improve consistency of standard (shall, should and can)

Introduction

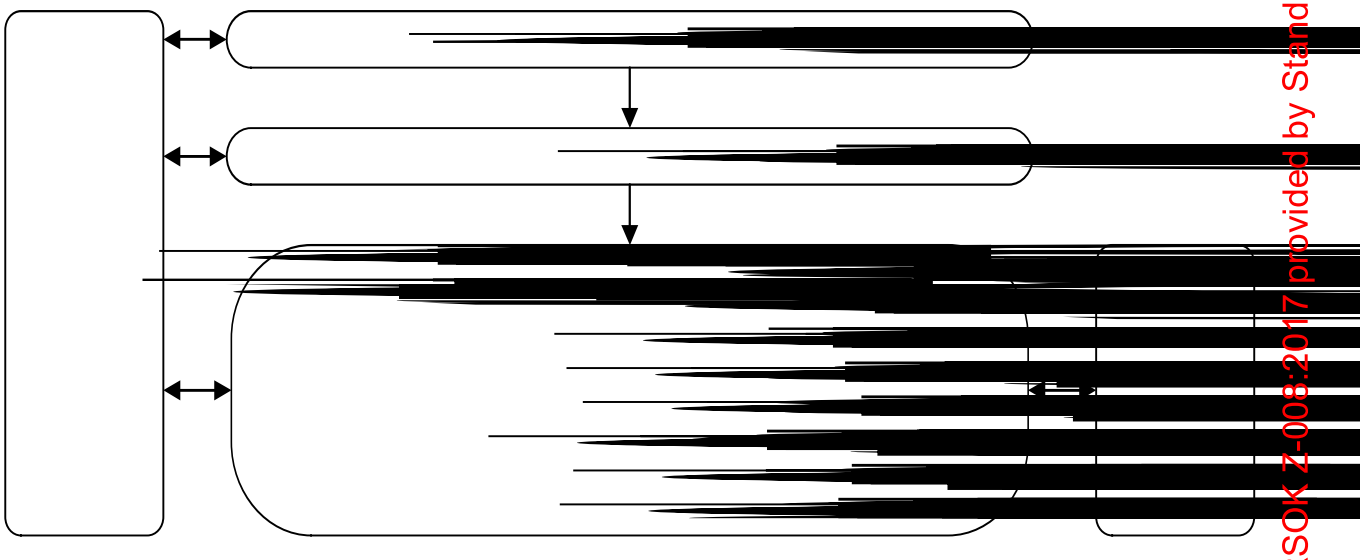
The purpose of this NORSOK standard is to provide requirements and guidelines for
- establishment of technical hierarchy,
- consequence classification of equipment,
- how to use consequence classification in maintenance management,
- maintenance management of technical barrier elements
- how to use risk and reliability analysis to establish and update PM programmes,
- how to aid decisions related to maintenance using the underlying risk analysis,
- spare part evaluations.

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

As a basis for preparation and optimisation of maintenance programmes for new and in service facilities all risk elements shall be taken into account, i.e. risks related to
- personnel,
- environment,
- production loss,
- direct and indirect cost including reputation.

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

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



Risk based maintenance and consequence classification

1 Scope

This NORSOK standard is applicable for preparation and optimisation of maintenance activities for all plant systems and items.

The consequence classification and the maintenance task selection process can be applied to all types of items, and, in principle, all types of failure modes and failure mechanisms are covered by this NORSOK standard. However, for some types of items, other specific analysis should be performed to identify failure characteristics, failure frequencies and mitigating tasks. This include, among others, load bearing structures, static pressure equipment, risers and pipelines.

This standard 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/maritime and energy plants/installations.

This NORSOK standard covers

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

2 Normative references

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

IEC 60300-3-11,	*Dependability Management Part 3-11: Application guide – Reliability centred maintenance*
IEC 60812,	*Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA)*
IEC 61508,	*Functional safety for electrical/electronic/programmable electronic safety-related systems*
IEC 61511,	*Functional Safety – Safety instrumented systems for the process industry sector*
ISO 17776,	*Petroleum and natural gas industries - Offshore production installations - Major accident hazard management during the design of new installations*
ISO 20815,	*Petroleum, petrochemical and natural gas industries – Production assurance and reliability management*
ISO 13702,	*Petroleum and natural gas industries – Control and mitigation of fires and explosions on offshore production installations – Requirements and guidelines*
ISO 14224,	*Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment, Edition 3, Sept. 2016*
NOG 070,	*Guidelines for the Application of IEC 61508 and IEC 61511 in the petroleum activities on the continental shelf*
NORSOK S-001,	*Technical safety*
NORSOK Z-013,	*Risk and emergency preparedness analysis*

For informative references, see Bibliography.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

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

Note 1 to entry: ISO 14224:2016 distinguishes between the terms mean active repair time (MART), mean time to repair (MTTR), mean time to restoration (MTTRes), and mean overall repairing time (MRT). See ISO 14224:2016 for further details.

Note 2 to entry: The mean active repair time (MART) is defined as "expected active repair time" in ISO/TR 12489:2013, 3.1.34. See also ISO/TR 12489:2013, Figures 5 and 6.

[SOURCE: ISO 14224:2016, 3.2]

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

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

Note 2 to entry: Further terms are given in ISO/TR 12489:2013.

[SOURCE: ISO 14224:2016, 3.3]

3.1.3
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: ISO 17776:2016, 3.1.1]

3.1.4
can
expression in the content of a document conveying expected or conceivable material, physical or causal outcome.

[SOURCE: NORSOK A-001:2016, A5]

3.1.5
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: ISO 14224:2016, 3.7]

3.1.6
condition monitoring
obtaining information about physical state or operational parameters

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

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

[SOURCE: IEC 60050-192:2015, 192-06-28]

3.1.7
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 ISO 14224:2016, Annex C.1.10 give examples of consequence classification.

Note 3 to entry: See also definition of Failure Impact in 3.1.17.

3.1.8
consequence classification
qualitative analysis of events and failures and assignment of the consequences of these.

Note 1 to entry: See definitions in 3.1.9, 3.1.10 and 3.1.11.

3.1.9
consequence HSE
health, safety and/or environmental consequence of an event

3.1.10
consequence production
effect with regard to production of a functional failure where effects of mitigation (e.g. spare parts, manning, tools) and compensation measures are not considered (= unmitigated consequence)

3.1.11
consequence other
other consequences as a result of a functional failure other than HSE or production consequence

Note 1 to entry: May also include monetary losses and loss of reputation.

3.1.12
corrective maintenance
maintenance carried out after fault detection to affect restoration

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

[SOURCE: ISO 14224:2016, 3.8]

3.1.13
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: ISO 14224:2016, 3.9]

3.1.14
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: ISO 14224:2016, 3.11]

3.1.15
equipment class
class of similar type of equipment units (e.g. all pumps)

Note 1 to entry: Annex A in ISO 14224:2016 gives equipment classes and also contains equipment-specific data for the equipment class.

[SOURCE: ISO 14224:2016, 3.18]

3.1.16
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 (3.1.17).

Note 2 to entry: A failure of an item is an event, as distinct from a fault of an item, which is a state [ISO/TR 12489:2013].

[SOURCE: ISO 14224:2016, 3.23]

3.1.17
failure cause
set of circumstances that leads to failure

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

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

[SOURCE: ISO 14224:2016, 3.24]

3.1.18
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 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 ISO 14224:2016, 3.32.

[SOURCE: ISO 14224:2016, 3.27]

3.1.19
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 ISO 14224:2016, 3.9, 3.11, and 3.40.

[SOURCE: ISO 14224:2016, 3.28]

3.1.20
failure mechanism
process that leads to failure

Note 1 to entry: The process can be physical, chemical, logical, or a combination thereof.

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

[SOURCE: ISO 14224:2016, 3.29]

3.1.21
failure mode
manner in which failure occurs

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

[SOURCE: ISO 14224:2016, 3.30]

3.1.22
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 ISO/TR 12489:2013, 3.1.18.

Note 2 to entry: See 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 ISO 14224:2016, 3.27.

[SOURCE: ISO 14224:2016, 3.32]

3.1.23
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 (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 20815:2008, 3.1.14).

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

[SOURCE: ISO 14224:2016, 3.33]

3.1.24
generic maintenance concept
GMC
set of maintenance actions, strategies and maintenance details, which demonstrates a cost-efficient maintenance method for a defined generic group of equipment functioning under similar frame and operating conditions

3.1.25
hazard
potential source of harm

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

[SOURCE: ISO 17776:2016, 3.1.9]

3.1.26
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 ISO/TR 12489:2013, 3.2.11.

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

[SOURCE: ISO 14224:2016, 3.35]

3.1.27
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/condition where no corrective actions are required.

[SOURCE: ISO 14224:2016, 3.40]

3.1.28
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: DNVGL-RP-G101:2010]

3.1.29
item
subject being considered

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

[SOURCE: ISO 14224:2016, 3.43]

3.1.30
main function
MF
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.

3.1.31
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 ISO 14224:2016, Annex C for a more detailed definition and interpretation of maintainability.

[SOURCE: ISO 14224:2016, 3.47]

3.1.32
maintainable item
item that constitutes a part, or an assembly of parts that is normally the lowest level in the equipment hierarchy during maintenance

[SOURCE: ISO 14224:2016, 3.48]

3.1.33
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: ISO 14224:2016, Figure 6 shows the main maintenance categories in more detail. ISO 14224:2016, Table B.5 presents the main types of maintenance activities commonly performed.

[SOURCE: ISO 14224:2016, 3.49]

3.1.34
maintenance effectiveness
ratio between the maintenance actual result and performance target

Note 1 to entry: See examples of KPIs in Clause 10 and ISO 20815:2008, Annex E that can be used for measure of maintenance effectiveness.

3.1.35
maintenance management
all activities of the management that determine the maintenance objectives, strategies, and the responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvements of methods in the organisation including economical aspects

[SOURCE: EN 13306:2010, 2.2]

3.1.36
maintenance strategy
management method used in order to achieve the maintenance objectives

[SOURCE: EN 13306:2010, 2.4]

3.1.37
may
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.

[SOURCE: NORSOK A-001:2016, A.5]

3.1.38
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: ISO 14224:2016, 3.67]

3.1.39
performance standard
PS
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: ISO 17776:2016, 3.1.17]

3.1.40
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: ISO 14224:2016, 3.77]

3.1.41
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 ISO 14224:2016, Figure 6.

[SOURCE: ISO 14224:2016, 3.78]

3.1.42
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: ISO 20815:2008, 3.1.37]

3.1.43
redundancy
existence of more than one means for performing a required function of an item

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

Note 2 to entry: Redundancy in IEC 61508:2010 is called “fault tolerance”.

[SOURCE: ISO 14224:2016, 3.80]

3.1.44
reliability
ability of an item to perform a required function under given conditions for a given time interval

[SOURCE: ISO 14224:2016, 3.81]

3.1.45
reliability centred maintenance
RCM
Systematic method for determining the respective maintenance actions and associated frequencies, based on the probability and consequence of failure

[SOURCE: IEC 60050-192:2015, 192-06-08]

3.1.46
required function
function or combination of functions of an item that is considered necessary to provide a given service

[SOURCE: ISO 14224:2016, 3.1.83]

3.1.47
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 ISO 20815.

[SOURCE: ISO 20815:2008, 3.1.44]

3.1.48
risk based inspection
RBI
a decision making technique for inspection planning based on risk, compromising the probability of failure and the consequence of failure

Note 1 to entry: These risks are managed primarily through equipment inspection.

[SOURCE: DNV-RP-G101:2010]

3.1.49
safety system
system which is used to implement one or more safety functions

Note 1 to entry: Safety function is in ISO/TR 12489:2013, 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 ISO/TR 12489:2013, Annex A. These systems are also cross-related in ISO 14224:2016, Table A.3.

[SOURCE: ISO 14224:2016, 3.86]

3.1.50
shall
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.

[SOURCE: NORSOK A-001:2016, A.5]

3.1.51
should
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.

[SOURCE: NORSOK A-001:2016, A.5]

3.1.52
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 sub functions.

3.1.53
tag/ tag number
unique code that identifies the equipment function and its physical location

[SOURCE: ISO 14224:2016, 3.91]

3.1.54
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: ISO/TR 12489:2013, 3.2.3]

3.2 Abbreviated terms

API	**American Petroleum Institute**
BOM	**bill of material**
CE	**Conformité Européenne**
CM	**corrective maintenance**
CMMS	**computerized maintenance management system**
EN	**European Standard**
FMECA	**failure mode, effect and criticality analysis**
GMC	**generic maintenance concept**
HSE	**health, safety and environment**
IEC	**International Electrotechnical Commission**
ISO	**International Organization for Standardization**
KPI	**key performance indicator**
LCC	**life cycle cost**
LCP	**life cycle profit**
MF	**main function**
NDT	**non destructive testing**
NOG	**Norwegian Oil and Gas Association**
OEM	**original equipment manufacturer**
OREDA®	**offshore and onshore reliability data**
P&ID	**process and instrumentation diagram**
PM	**preventive maintenance**
PS	**performance standard**
PSA	**Petroleum Safety Authority**
PU	**parallel unit**
QRA	**quantitative risk analysis**
RBI	**risk based inspection**
RCM	**reliability centred maintenance**
SIL	**safety integrity level**

4 Methodology for risk based maintenance management

4.1 General

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

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

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

4.2 Technical barrier elements

Safety and/or environmental barrier elements are defined as part of a major accident hazard management process, ref. ISO 17776 and NORSOK Z-013. The major accident scenarios are defined and barrier functions and barrier systems that prevents or mitigate the hazard are identified. Performance requirements are established as part of this analysis and the overall performance are documented in the form of Performance Standards (PS) or equivalent. The PS' will set requirements with respect to availability, capacity and performance of barrier functions. Reference is made to NORSOK S-001, ISO 13702, IEC 61508, IEC 61511, NOG 070, ISO/TR12489 and ISO 20815.

ISO 14224, F.4.2, lists the most common safety systems/components for an oil and gas installation with definition of critical/dangerous failure modes.

Technical barrier elements are the physical items that realize one or several of the barrier functions.

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

See Clause 7 for consequence classification of technical barrier elements.

See Subclause 8.4 for maintenance of technical barrier elements.

The technical availability of the barrier functions shall be controlled and documented at all times. The development of failure frequency and system unavailability shall be used as the basis for changing of test intervals and other mitigating actions to ensure compliance with functional requirements.

See Clause 10 for more information regarding reporting requirements.

4.3 Static process equipment

Static process equipment has a dual function, i.e. a function related to storing or transporting gas or liquids, and a containment function related to preventing external leakage of gas and liquids. The functional requirement to the storing or transporting of gas and liquids are covered by document, see Clause 7.

In order to establish an inspection programme for the containment function of the equipment, it is necessary to perform detailed evaluations similar to a FMECA and RCM process, usually named RBI. 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,
- consequence of leakage with respect to personnel, environment damages and financial losses.

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

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

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

There exist several standards for performing RBI analysis depending on type of object. Reference is made to DNVGL-RP-G101 for topside systems, DNVGL-RP-F206 for risers, DNVGL-RP-F116 for submarine pipeline systems and DNVGL-RP-0002 for subsea production systems. For refineries API RP 580 can be applied.

4.4 Risk decision criteria

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

This document will not define any generic criteria, but describe an example of such criteria. See also NORSOK Z-013, ISO 17776 and ISO 14224. The level of detailing in any risk matrix used is company specific, and can typical vary from a course 3x3 matrix to a more detailed 5x10 matrix.

The following principles should apply:

- the consequence- and risk matrices used for maintenance purposes should as far as possible be aligned with the overall company risk matrices but can be customized for maintenance purposes to aid proper planning and prioritizing of maintenance activities, and should be the same for all operations for a company in order to aid common companywide optimization and devote resources accordingly, as well as having a common terminology for communicating risk;
- further, 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 basically the same hardware;
- the consequence of loss of functionality (both loss of MF and sub functions) shall take into account the standby redundancy (see 3.1.43) and reduce the impact accordingly.

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

4.5 Input to maintenance engineering

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

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

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

- Barrier analyses (Performance Standards) (ref. NORSOK S-001 / ISO 13702);
- Safety Integrity Level analyses (SIL) (ref. IEC 61508/61511, NOG 070);
- Reliability analyses (ref. ISO 20815);
- Risk Based Inspection analyses (RBI) (ref. DNVGL-RP-G101);
- Life cycle cost/profit (LCC/LCP) (ref. ISO 15663);
- Maintainability studies;
- Working environment studies (ref. NORSOK S-002);
- Material handling studies;
- Manning studies;
- HAZOP (ref. NORSOK Z-013).

See the individual sections for input and relevance of the various studies to maintenance engineering.

Before any detailed maintenance analysis is performed, proper design and operational documentation shall be in place.

5 Maintenance management

The purpose of this clause is

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

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

Maintenance management is illustrated as a work process where products are produced with low HSE risks and high production performance. The basic model proposed as industry best practice is shown in Figure 1[1].

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

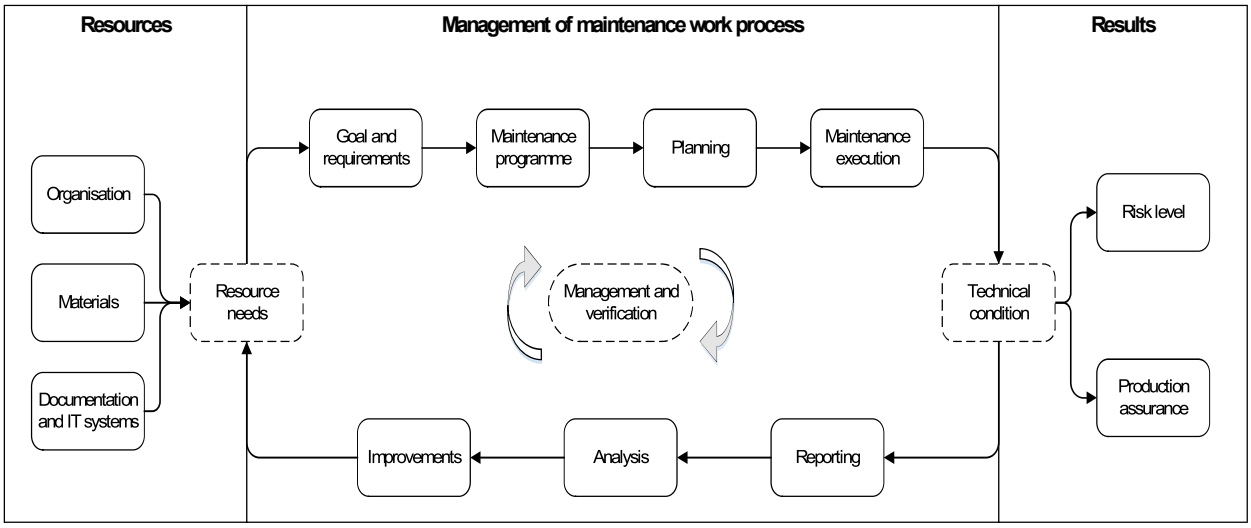


Figure 1 – Maintenance management process

[1] The model is based on PSA "Basisstudie" from 1998

Goals and requirements:

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

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

Maintenance strategies should be defined for the asset.

Maintenance programme:

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

This activity will typically involve the following:

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

See Clause 7 and Clause 8.

Planning:

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

This will typically involve the following:

- have a defined method and criteria for planning and prioritising of both preventive and corrective work based on its impact on HSE and production;
- group activities into efficient HSE and facility optimal groups/packages;
- the plans are regularly monitored and reviewed to access achievement, backlog, and efficiency.

See Clause 9.

Maintenance execution:

Execution includes preparations, work permits, carrying out work and reporting mandatory information on the work order. Maintenance and inspection work shall be executed in a safe and a cost-effective manner. System and equipment conditions shall be reported before/after repair for continuous improvement. Risk assessment shall be the basis for operational priorities.

This will typically involve the following:

- work execution shall be performed by competent personnel according to plans, procedures and work descriptions relevant for 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 data shall be reported to aid analysis and comparison vs. PSs.

See Clause 10.

Reporting:

Reporting involves 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.

This will typically involve the following:

- a set of KPIs shall be defined for monitoring and follow up of performance;
- key performance indicator performance outside set goals should be reported and acted upon;
- reports of safety performance, production and cost versus goals/budget should be available and communicated in the organization;
- a set of performance data shall be reported and compared to established PSs.

See Clause 10.

Analysis and Improvements:

This activity involves carry out analysis of historical maintenance data, and unwanted incidents related to maintenance, e.g. trend analysis, root cause failure analysis. Further the information should be evaluated and implement actions suggested based on the conducted analysis.

This will typically involve the following:

- a defined analysis process shall be in place addressing trigger values, analysis technique and responsibilities. The work should be documented and monitored;
- the analysis process shall include evaluation of maintenance effectiveness, i.e. to what extend the maintenance programme are handling the risks and performance requirements for individual systems or key components;
- the identified improvements, actions should be implemented and the effect should be monitored.

See Clause 10.

Organisation (Resources):

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

This will typically involve requirements to organisation, competence and roles/responsibilities.

Materials (Resources):

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.

Documentation (Resources):

Documentation in this context includes all documentation required to carry out and manage maintenance in an effective manner. This includes, but are not limited to, equipment/tag register, drawings and design details, historical maintenance data, maintenance task descriptions, spare part lists.

This will typically involve the following:

- maintenance data are organized into a database where technical information, plans and historic performance are readily available for users and decision makers;
- this documentation needs to be controlled, updated and made available to the relevant user.

Management and verification:

A key to good maintenance is a well organized management team taking responsibilities in implementing the principles herein and verifying the results. The management team shall ensure that the maintenance work processes are followed.

This will typically involve the following:

- the leaders shall define roles and 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 work flow 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.

Risk level (Technical condition):

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.

Production assurance (Technical condition):

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. An indicator of this would be the achieved production availability.

Cost (Technical condition):

Cost is here related to man cost for preventive and corrective work, spare parts and consumables, lost/deferred production that is under the control of the maintenance function.

6 Technical hierarchy

The technical hierarchy is a corner stone in maintenance management. It 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/equipment and how they are related. The purpose of the technical hierarchy is as follows:

- show 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 programme;
- planning of corrective work.

The level on which the maintenance objects are established is governed by practical execution and the individual need to monitor and control the different maintenance programmes. The technical breakdown of an installation shall as a minimum be broken down to a level were 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.

For corrective maintenance, where the work orders can be assigned to any tagged equipment, the cost will be traceable to a lower level, but even this costing should be possible to summarise to the same level as for the maintenance objects used for the PM programmes.

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

Reference is made to public coding standards:

- NORSOK Z-DP-002
- ISO 14224

7 Consequence classification

7.1 General

This clause describes how consequence classification shall be done, its workflow and relation to maintenance programmes. 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 7 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 FMECA/RCM/RBI analysis is recommended (screening process);
- establish PM programme;
- preparation and optimisation of GMCs;
- design evaluations;
- prioritisation of work orders;
- spare part evaluations.

7.2 Principles and work flow

Figure 2 shows an overall workflow related to classification.

The following principles apply:

- The consequence classification is done to identify critical equipment for HSE, production and cost;
- All physical tags/items 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 tag/items (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 and/or tags related to an installation shall be classified using the same classification scale – regardless which method and standard is used for the classification;
- The classification feeds in to a common risk model used for operational decision making thus they need to be comparable;
- A functional hierarchy is established (MFs and sub functions). This is normally not stored in the CMMS but used during the classification process. See Annex D.2 for an example of a functional breakdown of a system. Equipment/maintenance objects are assigned to the relevant sub function;
- The consequence of loss of containment is assessed as a separate failure mode from the loss of function;
- Barriers are defined via safety analysis (e.g. quantitative risk analysis) in the design or modification process. As such these systems and equipment are already identified and its safety function defined, normally with high consequence for HSE;

  Note to entry: Barrier functions identified as part of a major accident hazard management process can be different from main- and sub functions in the consequence classification process described in this document.

- Technical barrier elements shall be marked in the maintenance management system, and if not done as part of the barrier analysis, can be done as part of the consequence classification analysis based on the barrier analysis. This will typically be which performance standard(s) the item is part of;
- The consequence classification only assesses the primary function of an item (i.e. pumping, storing) and not 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/function. See Subclause 8.3 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. Examples of information to be assigned to each tag are
  - functional failure/loss of function – HSE consequence,
  - functional failure/loss of function – production consequence,
  - functional failure/loss of function – cost/other consequence,
  - consequence of loss of containment,
  - barrier function identifier,
  - redundancy.

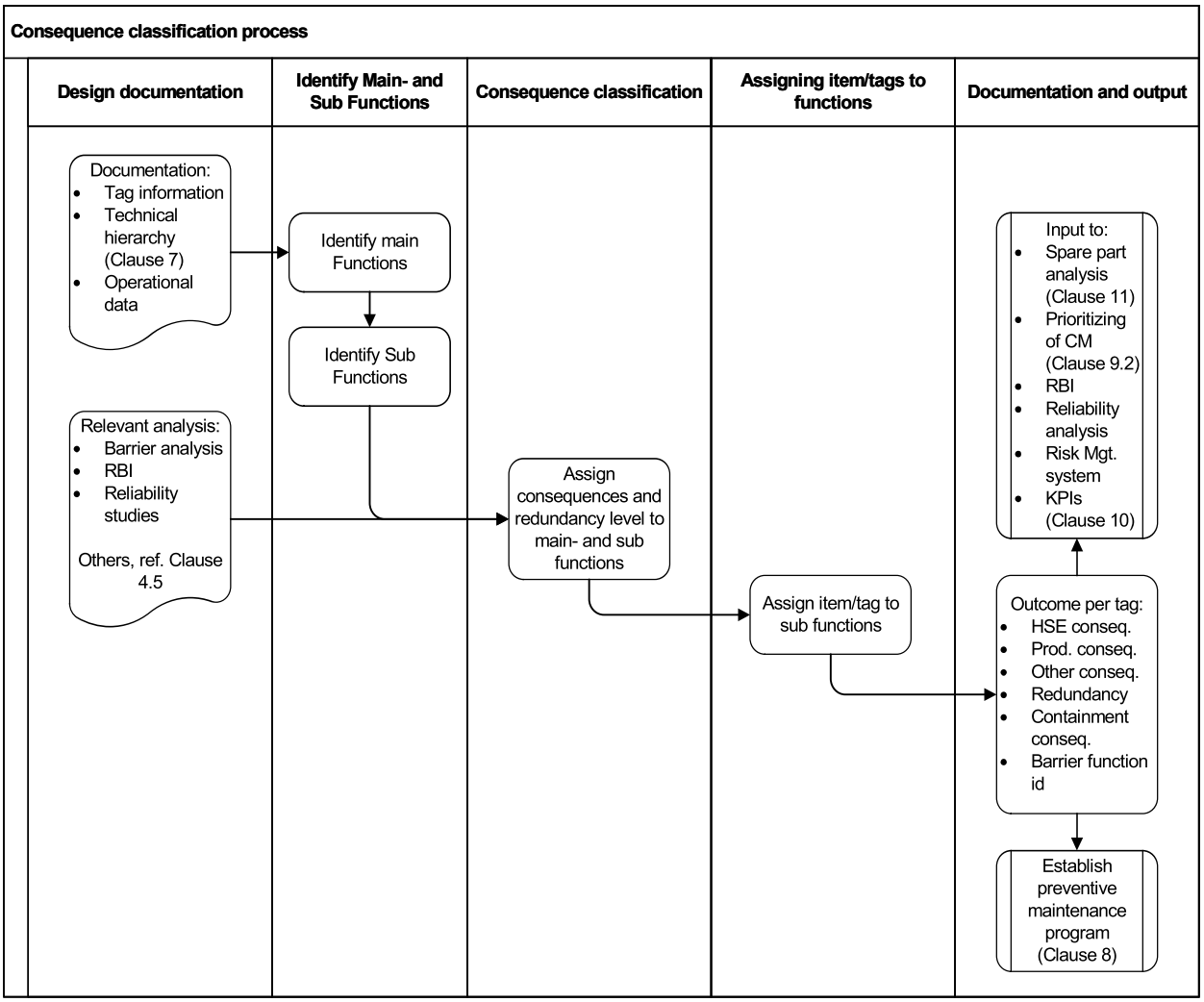


Figure 2 – Consequence classification process

7.3 Consequence classification of main and sub function

The functional classification work process is described stepwise below, and illustrated in Figure 2.

No	Step	Activity
1	**Technical information**	• Technical information and documentation regarding systems and items is 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 6 regarding technical hierarchy.
2	**Input from other analyses**	• See Subclause 4.5 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 readily identification in the CMMS system. The functional requirements are carried forward to the maintenance programme to maintain these functions. • Containment: For the tags/systems that are containment related, results from a RBI analysis can be used as a guide to the consequence of loss of containment. • Availability: Production assurance studies (e.g. RAM) 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 sub functions**	• MFs are split into sub functions. In order to simplify the consequence assessment, the sub function level can be standardised for typical process equipment with pre-defined terms. See Annex B. • The standard list of sub functions has to be supplemented with other sub functions relevant for the system configuration.
5	**Assign MF redundancy**	• MF redundancy shall be specified, see Table C.2 for example of redundancy definitions. • In case of safety systems or protective functions with redundancy due to functional reliability or regulatory requirements, the redundancy effect should not be counted for.
6	**Assign MF consequences**	• The entire MF failure consequence is assessed in terms of the state where the MF no longer is 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.

No	Step	Activity
		• Other mitigating actions are not considered at this stage, i.e. like 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 Subclause 4.4.
7	**Assign sub function redundancy**	• If there is redundancy within a sub function, the number of parallel units and capacity per unit shall be stipulated, see Table C.2 for example of redundancy definitions.
8	**Assign sub function consequences**	• The consequence on system/plant of a fault in a sub function is assessed with respect to HSE, production and cost according to the same principles as outlined for MF.
9	**Equipment mapping to function**	• The equipment (identified by its tag numbers, see Clause 6) carrying out the sub functions are assigned to the respective sub functions. • If equipment performs more than one sub function (e.g. some instrument loops), it is assigned to the most critical sub function. • All equipment (identified by its tag number) will inherit the same description, consequence classification and redundancy as the sub function of which they are a part. See Annex C for an example.
10	**Result per equipment**	• Consequence analysis shall be documented according to Subclause 7.4 and the key data be available in the CMMS.

7.4 Documentation of consequence classification

A sound principle is to make the assessment 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;
- definition of consequence classes;
- MF description;
- sub function description;
- assignment of equipment (tags) to sub function;
- assessment of the consequences of loss of MFs and sub functions for all consequence categories, including necessary arguments for assignment of consequence classes;
- assessment of MF and sub function redundancy;
- any deviations shall be documented and explained.

8 Maintenance programme

8.1 General

This clause describes how the consequence classification shall be used to establish a risk based preventive maintenance programme. The purpose of a maintenance programme is to control or mitigate risks associated with degradation of a function. Maintenance activities includes predetermined- and condition based activities. The programme shall include activities and maintenance intervals per item.

The consequence classification, as described in Clause 7, shall be used as a basis for the selection of the maintenance activities and –intervals.

The maintenance programme shall be risk based and critical failure modes shall be managed at all times and mitigated when necessary.

Using Generic Maintenance Concepts (GMC) is an efficient and cost effective way of developing a risk based maintenance programme, see Subclause 8.5.

8.2 Work flow for establishing preventive maintenance (PM) programme

8.2.1 Task selection

The results from the Consequence Classification as described in Clause 7 shall be used as an input to the preventive maintenance programme 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 3 and described below.

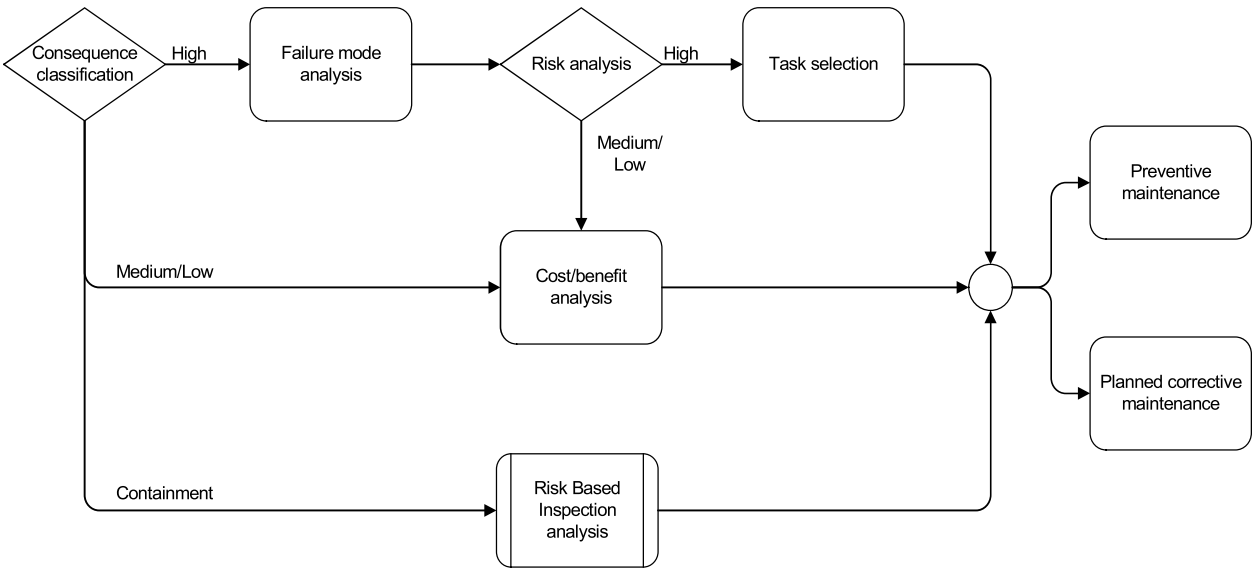


Figure 3 – Establishing maintenance programme for new plants

For items classified with high consequence 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 consequence of failure on operation or cost, in order to maintain operational regularity and reduce cost.

The recommended approach is to perform a Failure Mode Effect and Criticality Analysis (FMECA) to identify critical failure modes and the contributing failure mechanisms that needs to be controlled or mitigated.
See IEC 60812 (or similar standards) for more information on how to perform a 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 (RCM) 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 to detect failure, failure patterns, the availability of condition monitoring, etc.
See IEC 60300-3-11 (or similar standards) for more information on how to perform a RCM analysis.

Failure modes that are not critical to the function of an item, as well as items performing functions that do not have 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.

Items with medium or low consequence of functional failure may still have failure modes that render them unsafe in operation and which needs to be controlled or mitigated. See Subclause 8.3 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 when experience is gained for the specific installation/items.

For items with similar failure modes and -mechanisms, and operating under similar conditions, Generic Maintenance Concepts (GMC) can be developed in order to perform the task selection process more efficiently. See Subclause 8.5 for more information.

8.2.2 Maintenance programme

The identified preventive maintenance tasks shall be scheduled in a maintenance management system.

In establishing the preventive maintenance programme the impact on operation should be minimized. E.g. possibilities for condition monitoring, establishing efficient work packages, group similar maintenance task into maintenance campaigns and planning of intrusive maintenance to planned shutdowns/turnarounds.

In developing the maintenance programme local knowledge and experience shall be utilized. This could include working environment, work load, maintainability, etc.

The created work orders shall as a minimum contain information about priority, start-/end date, overdue date, required spare parts and resources, personnel, task duration, shutdown requirements, etc. for proper planning and follow up of maintenance. See Clause 10.2 for more information.

8.3 Equipment characteristic unsafe failures

Some items may suffer failure modes that render them unsafe in operation but which do not harm the functionality of the item. Example is damage to electrical insulation causing short circuit dangerous for personnel touching the item. The electrical failure is usually not considered a functional failure but represents a dangerous situation. These failure modes or failure mechanisms related to the

characteristics of an item shall be identified and be 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 Subclause 8.2.1 and can be documented as part of a Generic Maintenance Concept (see Subclause 8.5).

The CE (Conformité Européenne) marking of equipment shall include an assessment of personnel risk as part of the information for use. Relevant standard is ISO 12100.

8.4 Maintenance of technical barrier elements

Safety- and environmental barriers are usually defined in barrier analysis based on ISO 13702 and NORSOK S-001. The items performing a barrier function needs to be identified and the selection of maintenance task for items with a barrier function (safety and/or environment) are based on the same work process as other items, as described in Subclause 8.2 (i.e. identification of failure modes and activities to control or mitigate these failure modes).

The performance of the technical barrier element shall be described so a maintenance operator can test, verify and report the condition of the item performing the barrier function. This especially applies to technical barrier elements with hidden failures (dangerous undetected failures) which are not normally evident to operation- and maintenance personnel.

For items with function tests to detect dangerous undetected failures, the maintenance work order in the maintenance management system shall as a minimum then contain:

- description and requirements of test (e.g. no maintenance before function test);
- failure characteristics (e.g. valve do not close within specified time);
- acceptance criteria (e.g. closing time 12 seconds);
- how the result of a failure shall be reported (e.g. “create notification in CMMS with failure mode Fail To Close”).

A system shall be in place to analyse test results and verify that the availability of the barriers are in accordance with design and operational requirements, typical SIL requirements and Performance Standards.

8.5 Generic maintenance concept

Performing FMECA- and RCM analysis on all items with high consequence individually on an installation can be costly and time consuming. Using Generic Maintenance Concepts (GMC) is an efficient and cost effective way of developing a risk based maintenance programme, standardizing maintenance activities and capturing and sharing company experience and knowledge.

8.5.1 General

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 frame 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 a FMECA/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 experience and technology becomes available, see Annex D.

For barrier functions: the performance requirements, the corresponding acceptance criteria and critical failure modes shall be defined on the concepts.

The GMC shall be established based on the same task selection work process as described in Subclause 8.2 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 documentation will differ depending on the complexity of the equipment and the risk attached.

8.5.2 Application of generic maintenance concepts (GMCs)

Generic maintenance concepts may be developed in order to

- establish a company's minimum requirements to maintenance,
- reduce the effort in establishing the maintenance programme as similar items/technologies are pre-analysed,
- ensure uniform and consistent maintenance activities,
- facilitate analysis of group of items,
- provide proper documentation of selected maintenance strategies,
- ensure experience transfer between plants with similar technology and operation.

Generic maintenance concepts are applicable for all types of items covered by this document.

A GMC can be utilized when

- the group of equipment has 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.

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/RCM should be performed for each individual equipment package in order to capture the complexity of these kind 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.

8.6 Update maintenance programme /Continuous improvement

A continuous improvement process shall be in place in order to enhance safety levels and at the same time reduce down time and cost. Reference is made to the Clause 5 and Figure 1 – Maintenance management process.

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. From a plant wide perspective it shall be possible to break these acceptance criteria down to system and item/equipment class levels (co-related targets) and were the performance of the individual technical barrier elements can be verified.

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.
Reference is made to Clause 10 for reporting, KPIs and analysis.

8.6.1 Update maintenance programme

A maintenance programme 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 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 may point towards extension of intervals or omitting certain tasks.
- the operational environment has changed causing different consequence and probability:
  - less or more production;
  - change in product composition.
- cost of maintenance different from expected:
  - new technology that could make the maintenance more efficient (like new methods for condition monitoring) is available;
  - updated regulations;
  - information from vendor;
  - modifications or replacement with new equipment.

The evaluation shall be based on historical data and experience. A process diagram to update a maintenance programme is shown in Figure 4. If it is a safety system, an evaluation of number of failures per tests versus PS requirements shall be performed. 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 maintenance programme and GMC (if relevant) should be updated, and implemented in the maintenance plan.

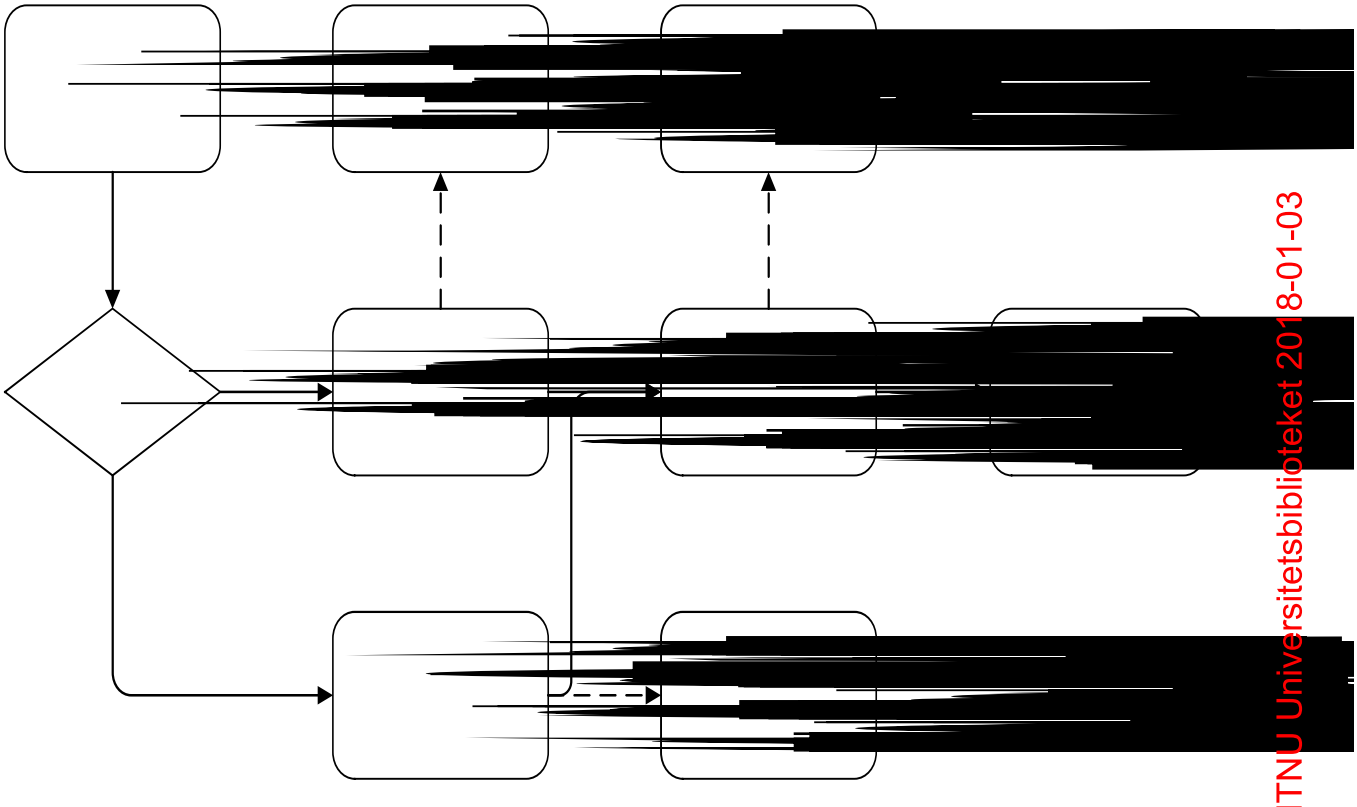


Figure 4 – Process for updating maintenance programme

8.7 Maintenance programme and handling of ageing

Most maintenance programmes are based on a relatively constant failure frequency and not considering the ageing development that systems can suffer. However, the maintenance function shall at any time have an overview of the ageing development for its components, and do maintenance and upgrading to ensure safe and reliable operation. The same principles for continuous improvement, as described in Subclause 8.6, 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 reaching its intended lifetime.

The cost regarding aging and displacement or restoration of an item should be taken into consideration in the Life Cycle Cost (LCC) analysis (ref. ISO 15663), preferably in the design phase. In the operation phase a register of risk ranked vulnerabilities can be made with expected future operating cost and modification/capital cost requirements.

A more dedicated effort may be required when approaching the intended lifetime for the plant. Such an effort involves the following:

a) evaluate operational and degradation history. Any incidents with large degradation, abnormal operation, etc. should be identified as well as any detrimental effect of modifications done to the unit. Collection and verification of system documentation and “as-build” documentation;
b) assessment of current condition/”as-is” condition;
c) evaluate the future ageing in view of the planned future operation and load planned for the asset:
   1) are there any ageing phenomena that have not been seen so far but are under development?
   2) are the barrier function status and development according to requirements?
   3) will any items/system become obsolete so that spare parts no longer can be purchased?
d) based on c) decisions need to be made regarding:

1) any updates to the maintenance programme (and GMC as necessary) or changes in the spare part holding strategy,
2) replacement or modifications of single components or larger units,
3) any operational constrains for the unit in view of ageing,
4) dedicated analysis for e.g. structure.

See NOG 122 for required documentation of maintenance and inspection in connection with formal application for consent of extended lifetime.

9 Maintenance planning

9.1 Maintenance planning and scheduling

There shall exist a maintenance plan covering both preventive and corrective maintenance. Safety critical and/or operation critical maintenance activities shall be included in the installation total activities plan.

The PM programme is established as described in Clause 8. This programme 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 shall include the necessary preparation for the activity, such as materials, personnel, tools, access, impact on operations, etc.

9.2 Prioritising maintenance activities

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

Prioritizing 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. Backlog related to the plan shall be prioritised based on risk, i.e. probability and consequence of failure.

Prioritization of corrective maintenance shall be done based on the risk the failure represents, described as consequence and failure impact/probability of failure. Some companies call this process “Risk Based Work Selection”, and have implemented it in their maintenance management system. Figure 5 shows an example of such a work flow, i.e. a selection of which corrective work orders to prioritize.

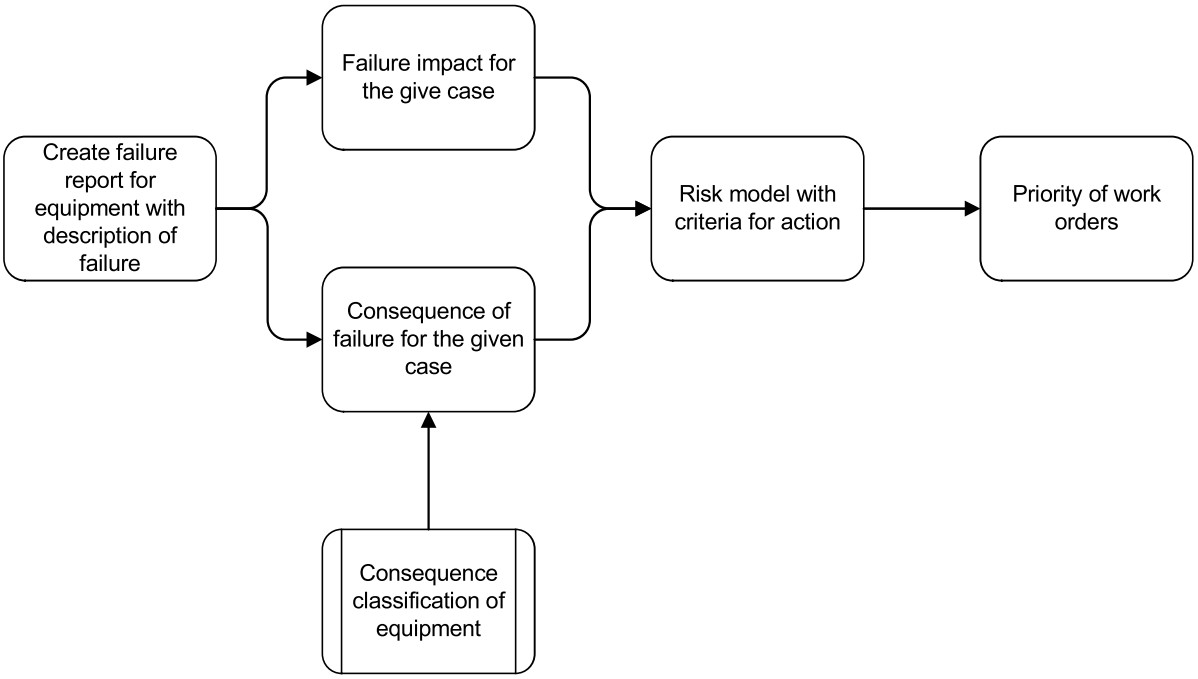


Figure 5 – Priority of corrective work orders

The process involves the following:

- assigning the consequence of failure to the case. It can be assigned via the consequence classification of equipment on overall functional level. This consequence shall always be supplied by information regarding the actual failure mode, the operational state of the plant, possibilities for re-routing the process, etc. 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 Subclause 8.3) for low consequence equipment;
- assigning the failure impact, see Table 1 and Subclause 3.1 Terms and definitions. 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;
- the risk associated with the consequence and probabilities as well as actions from this risk (priorities) shall be defined in given criteria e.g. via a risk matrix. Table C.3 shows an example of a risk model described as a risk matrix used to determine the priority;
- priority. Compensating operational actions used to temporarily maintain the function can be described as redundancy;
- compensating measures shall be in place when failure on the safety critical functions.

Table 1 – 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 actual operation may continue for a short period of time. A critical failure result 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.	

10 Reporting, analysis and improvements

10.1 General

Reporting and analysis of maintenance performance is required in order to ensure continuous improvement. Below is described how this should be done.

10.2 Reporting

Table 2 shows some relevant failure and maintenance data related to maintenance activities, that as a minimum should be recorded. The ISO 14224 standard gives requirements and recommendations for reporting of data related to maintenance, see ISO 14224 for a more complete overview and further details. The need for reporting will vary between systems and equipment, and need to take into account field personnel resource utilisation.

Table 2 – 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 down time

10.3 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, backward-looking) KPIs and proactive (leading, forward-looking) KPIs should be selected.

Examples of some relevant KPIs are shown below:

Table 3 – Examples KPIs

KPI	Purpose	Comment
Preventive maintenance workload	Indication of amount of preventive maintenance work	
Corrective maintenance workload	Indication of amount of corrective maintenance work	
PMs overdue	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	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

See ISO 14224, Annex E, and EN 15341 for examples of relevant KPIs.

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.

10.4 Analysis and Improvement

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

The organization 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 losses;
- cost of single failure events in terms of downtime, repair cost or spare cost;
- number of repeated failures over a given time period for key components;

- hidden failures (exceeding requirements) detected during test;
- technical condition assessments.

Based on the event(s) the root cause(s) should be identified and necessary actions taken to avoid reoccurrence. The problem at question can be either single discipline or multidiscipline. The team should be allocated to the actual case, and will 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 and/or acceptance criteria can involve adjustment of the maintenance programme. The results may also be used for making decisions regarding replacements, modifications, and upgrades of systems in 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 a key to continuous improvement of performance of a plant and an organisation. Dedicated efforts should be to implement a proactive and systematic continuous improvement process.

11 Spare parts evaluation

11.1 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 7) and other relevant analysis like reliability analysis and barrier analysis (see Subclause 4.5 for more examples).

The PM programme 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 is 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 shall state the needed spare parts for the activity.

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

11.2 Work flow for evaluation of spare parts

Figure 6 gives an overview of the work flow for evaluation of spare parts. Subclause 11.3 to 11.5 details the content in each box.

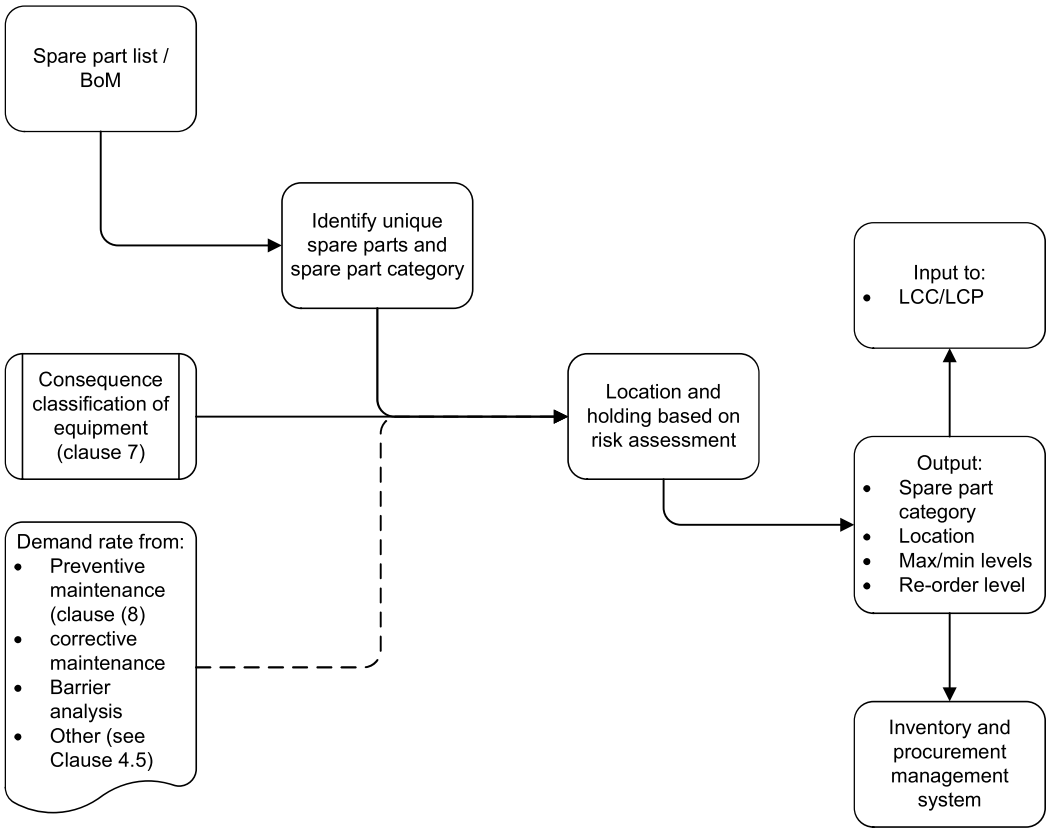


Figure 6 - Evaluation of spare parts

11.3 Spare part categories

Spare parts can be 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;
  - 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;
  - also called insurance spare part.
- 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).

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

11.4 Location and holding

Spare parts are normally held at various locations. Determining the optimum location for a spare part shall be done by use of a risk model where the dimensions are consequence of not having the spare parts in place and the demand rate. See Annex C, for an example of a risk matrix for use to determine location. 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 7.

11.5 Reorder level and order quantity

The re-order level and order quantity are important parameters to control 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.

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 Personnel and resources

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

- maintenance personnel with specific experience from different type of systems/equipment, which typically will involve mechanical, instrument, electrical and corrosion/inception qualification on senior level;
- maintenance planners and/or maintenance supervisors;
- operation and process personnel with process/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, by vendors or consultants.

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'). 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/plant air, heating/cooling medium
Cementing	
Circulating	Heating/cooling medium
Compressing	Gas export/injection
Cooling	
Detecting	Fire and gas
Distributing	(Main/emergency) power, hydraulic, tele
Drying	Air, gas
Expanding	
Filling	Lubrication oil
Filtering	
Fire fighting	Sprinkler, deluge, water spray, foam, aqueous film foaming foam, hydrants
Generating	(Main/emergency) power
Heating	
Injecting	Chemicals, gas, water
Life Saving	Mob, lifeboat, basket, raft, escape chute
Lifting	Deck crane, personnel, goods
Logging	Well, production, mud
Manoeuvring	
Metering	Fiscal (gas/oil), CO_2
Pumping	Oil/gas export, bilge, seawater
Regenerating	Glycol
Scrubbing	
Separating	Production, test, cyclone- (water/sand/oil), centrifuge
Storing	Chemicals, potable water, lubrication/seal oil
Transferring	Oil/gas pipe (riser)

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 is shown on Figure A.1 and Figure A.2.

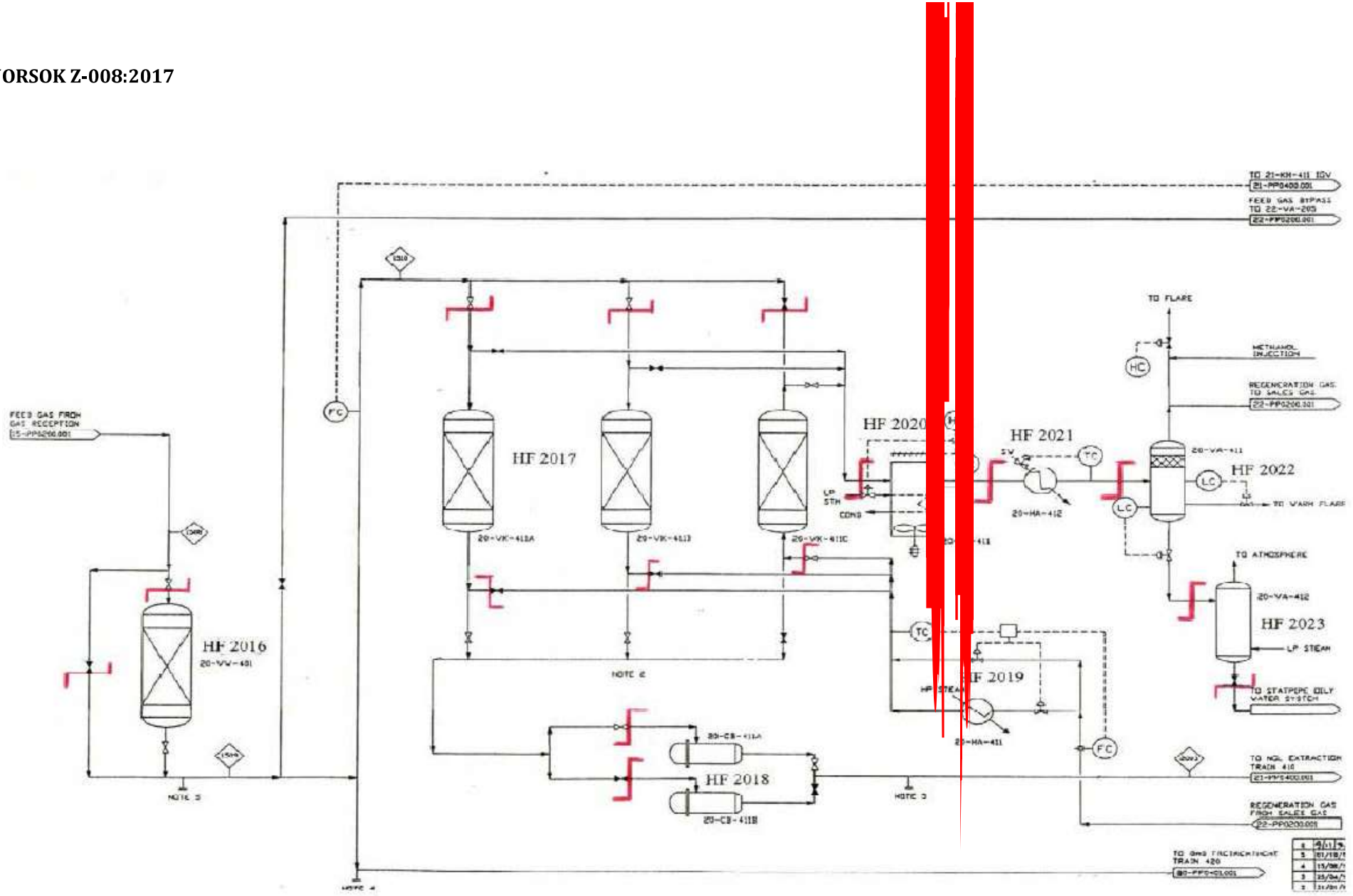


Figure A.1 – Flow diagram showing borderlines between MFs (HF2017, HF2020)

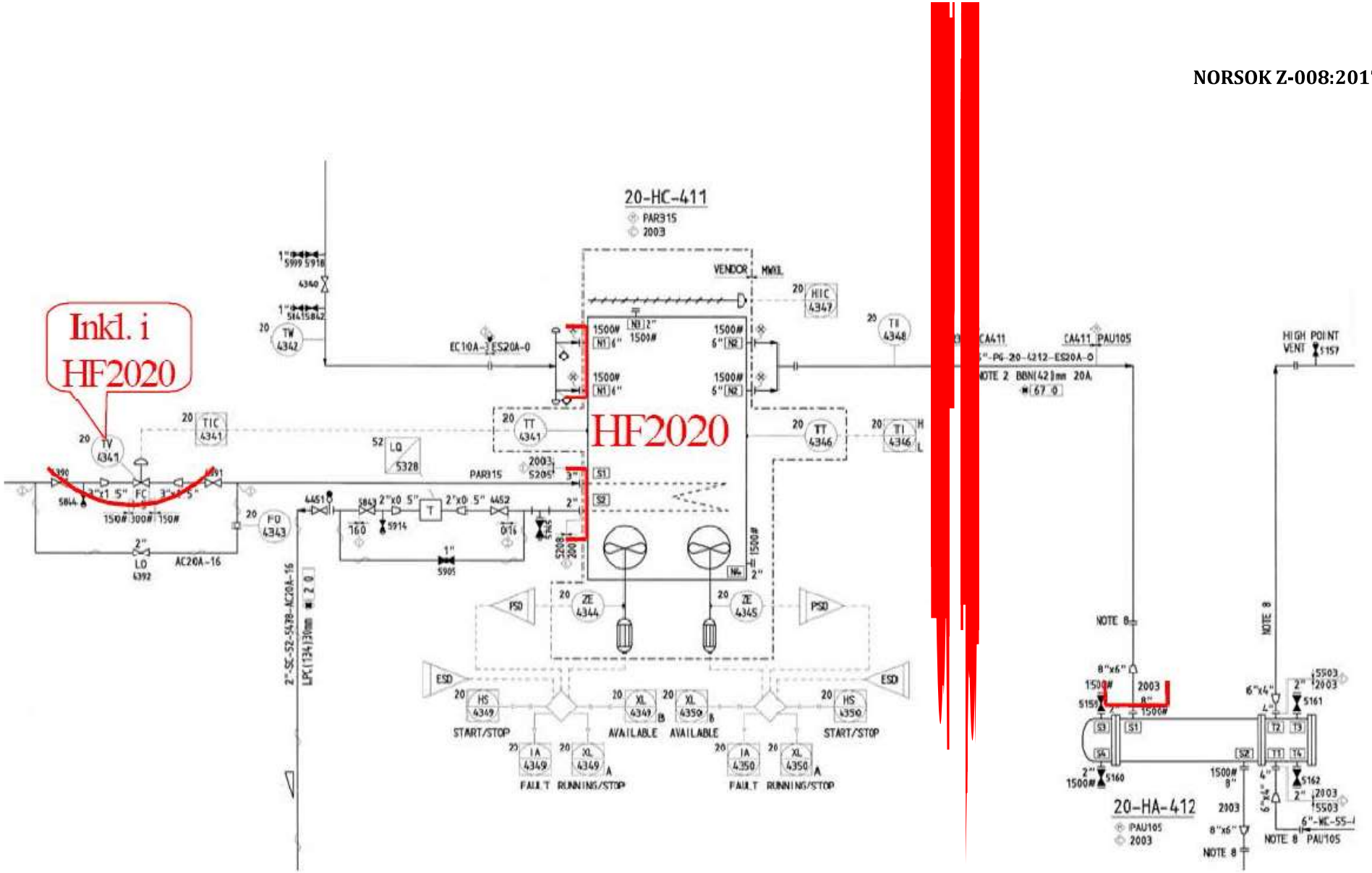


Figure A.2 – P&ID showing borderlines for MF HF2020

Annex B
(informative)

Simplifying consequence assessment of standard sub functions

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

An example of guidelines for the standardised sub functions for one project is shown in Table B.1.

Note to entry: 'Other functions' have to be assessed independently.

Table B.1 – Project guideline example of consequence assessment of standardized sub functions, based on the MF consequence assessment

Standard sub function	Classification of loss of function				Comment
	RED	HSE	PROD	Other	
Main task	MF	MF	MF	MF	
Pressure, relief	Config-uration	H	L	L	**RED:** No redundancy for the failure mode 'Fail to operate on demand'
Shut down, process	A	H	L	L	**RED:** No redundancy for the failure mode 'Fail to operate on demand'.
Shut down, equipment	MF	M	L	MF	**Other:** Inherits the highest consequence from the MF
Controlling	MF	MF	MF	MF	
Monitoring	MF	M	L	L	
Local indication	MF	L	L	L	
Manual shutoff	MF	(MF)	(MF)	(MF)	

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

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.

ISO 14224 gives another example of failure consequence classification.

Table C. 1 - Example of consequence classification matrix

Consequence category	C1	C2	C3
Safety	No potential for injuries. No effect on safety systems.	Potential for injuries requiring medical treatment. Limited effect on safety systems.	Single/multiple fatality or serious personnel injuries. Render safety critical systems inoperable.
Environment	No/minor spill	Medium discharge	Major discharge
Production	No production loss	Delayed effect on production (no effect in x days) or reduced production	Down time loss of production DT > X days
Other	No operational or asset cost consequences Cost < X (USD)	Moderate operational or asset cost consequences X < Cost < Y (USD)	Significant operational or asset cost consequences Cost > Y (USD)
Containment	Non-flammable media Non-toxic media Natural/normal pressure /temperature media	Flammable media below flashpoint Moderately toxic media High pressure/ temperature media (>100 bar/80 °C)	Flammable media above flashpoint Highly toxic media Extremely high pressure /temperature media

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 7, the consequence classification is used to plan activities and prioritize resources.

The consequence classification is 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 then 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.

If the due date is not met, this should be flagged, and in case of work order 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 task based on the consequence classification.

Table C. 3 – Example of priority/time to repair based on classification

Consequence	Priority/ 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 due date and prioritizing 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 demand rate gives 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 have 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 environment.

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

Consequence / Demand rate	Low	Medium	High
First line spare parts, frequently used.			
Not frequently used.			
Capital spare parts. Seldom or never used.	No stock	No stock	Holding optimized by use of risk assessment case by case

C.4 Risk matrix

The consequence classification gives, as the term imply, the consequence in the case of loss of function. As part of performing a FMECA and RCM analysis the probability of each failure mode is defined. The probability gives an indication about 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 items failure mode, and the overall risk for each item.

From the FMECA/RCM-analysis the probability of the failure mode and failure mechanism is defined. If defined as part of a generic maintenance concept, 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 Annex D.3 for an example.

When one generic maintenance concept is applied to two different items with different consequence classification or redundancy the suggested maintenance activities and intervals can be different. 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 Annex D.4 for an example of a generic maintenance concept.

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 item where there is little data available to establish a quantitative failure frequency.

Annex D
(informative)

Practical examples

D.1 Technical hierarchy

The level of detail with regards to tagging is in many ways a deciding factor to ensure that the equipment will receive the adequate maintenance. On the Norwegian Continental Shelf there is an industrial heritage of tagging to a detailed level where even instrumentation and equipment in support of MFs and sub functions are tagged The tagging is to be consistent from drawings, the actual equipment in 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.

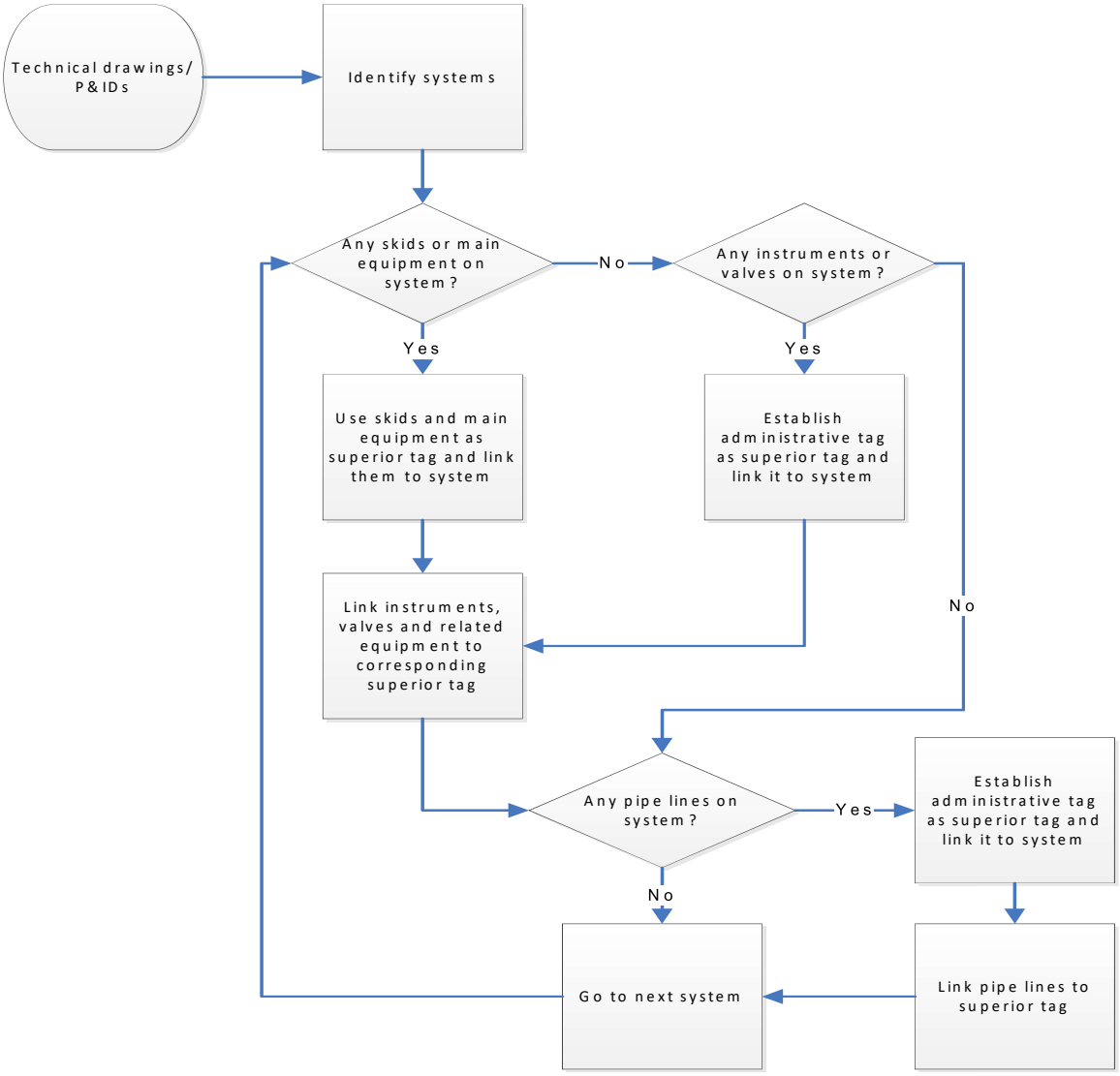


Figure D.1 – Work process technical hierarchy

To establish a technical hierarchy it is necessary with a set of technical drawings, e.g. flow and one-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. The usage of system numbers may vary from plant to plant NORSOK Z-DP-002 uses system numbers between 00 and 99. Other standards like SFI [Ship research institute of Norway (Skipsteknisk Forskningsinstitutt)] would have a 3 digit numbers as system numbering, but the principles may be similar.

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. 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. The instruments, valves and other kinds of equipment are then linked to the administrative tags. In instrument loops one of the components can represent the whole loop e.g. a transmitter or valve, while the rest of the loop lie beneath.

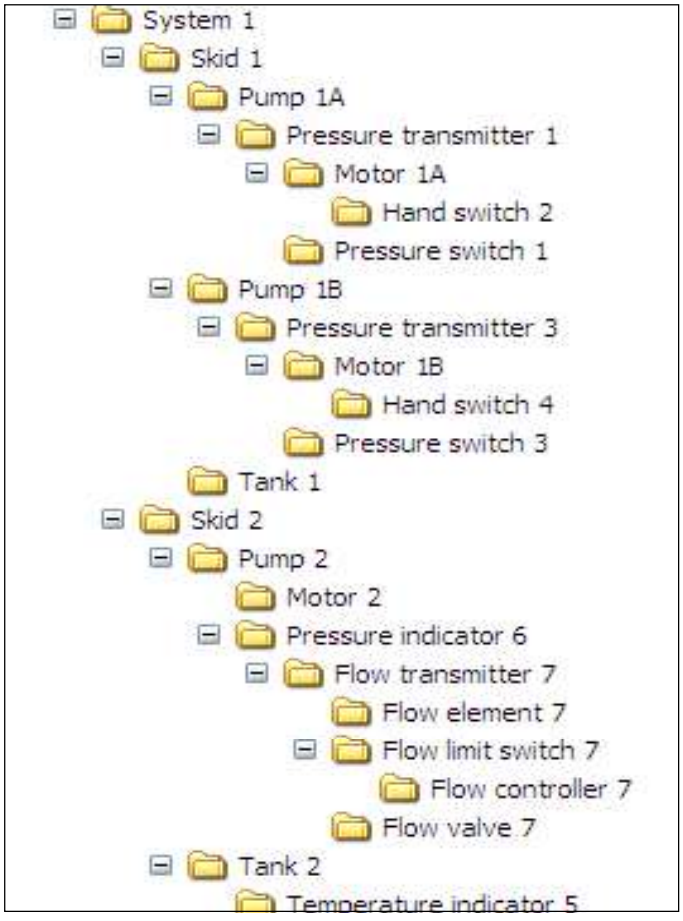


Figure D.2 – Technical hierarchy

D.2 Functional hierarchy

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

The 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 sub functions for one of these MFs are illustrated as an example.

Each tag within one sub function 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 a MF (2701 Scrubbing), with standard sub functions listed, is shown in Figure D.4. This MF consists of two parallel units, each able to perform 100 % of the scrubbing function in 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 number of parallel units and capacity (Cap: 50 %, 100 %).

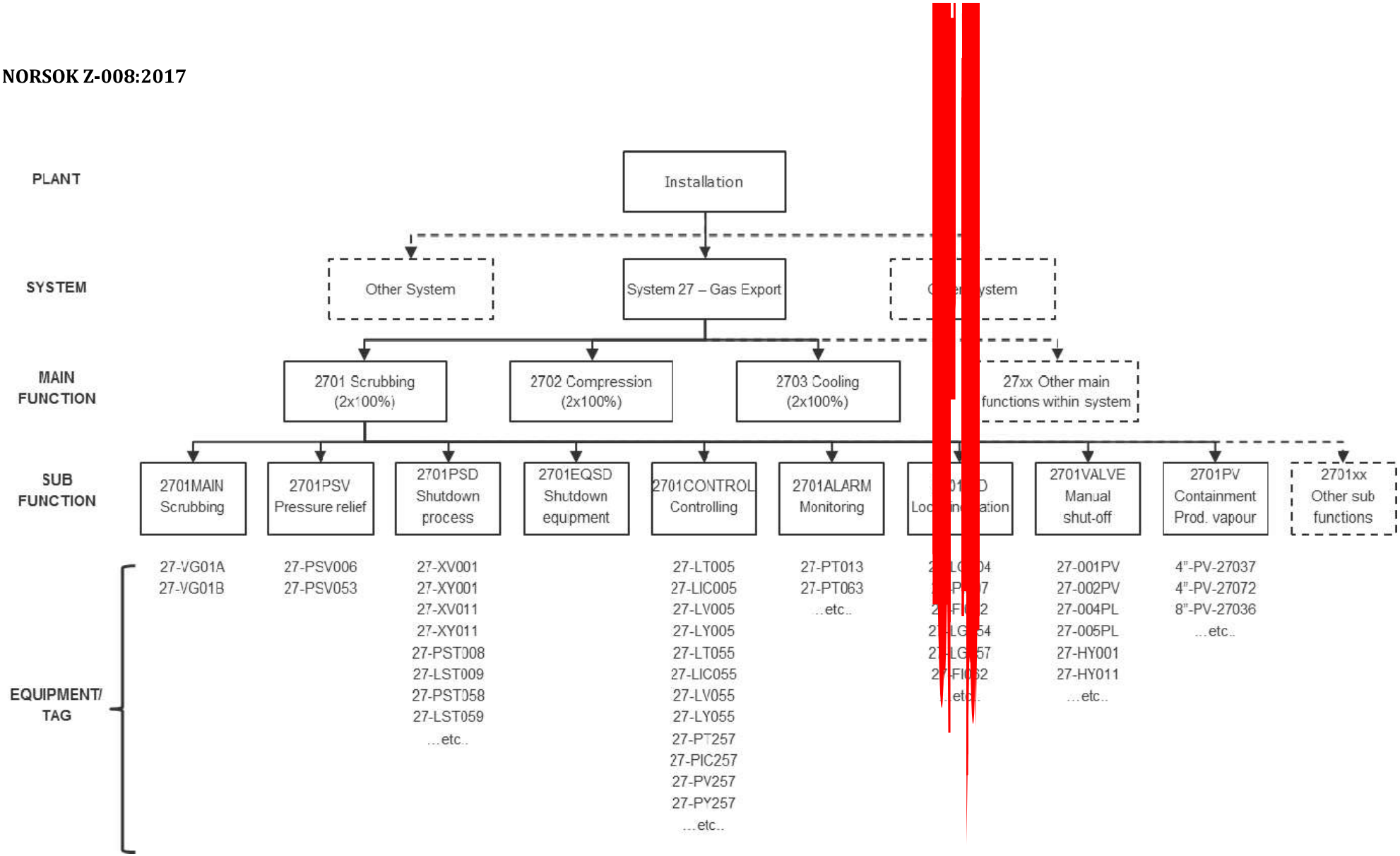


Figure D.3 – Functional hierarchy, example with standard sub function and classification

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 consequence.	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

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

D.4 Documentation of generic maintenance concept (GMC)

A GMC is a set of maintenance actions, strategies and maintenance details, which 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. 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 no concept is applicable, should be linked to same concept as the superior tag, i.e. instrumented valve.

Each concept should specify which type of equipment the concept is covering and which type of equipment that is excluded. Each concept should be detailed at such 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 for the actual functional location which the concept is linked to.

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

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

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 visual check	For outside motors, check external and internal condition of junction boxes. If the JB has flame slits, check and lubricate.	ELEC	N	N	M	12	12	12	1,5	ELEC x 1,5	1,5
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

Failure mode analysis:

Preventive Activity(s)	Failure Mode	Failure Mechanism	Failure Cause	Frequency (yrs/failur	Analysis eference	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	2-5 Years	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)
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	ISO 14224 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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