Appendix A05-1-1 Project specific RCM analysis method requirements

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1. Introduction

This Appendix details the project specific requirements for developing a maintenance program for the delivery to Norske Tog. The project specific requirements defines in more detail the process described in recognized standards or other method descriptions used for the maintenance program development.

1.1 Abbreviations and definitions

In general, “definitions” and “abbreviations” in EN50126-1 (2017) and EN 13306 (2017) chapter 11 apply.

Term	Description	Source if applicable
LCC	Life cycle cost	EN 13306
RAM	Reliability, availability and maintainability	See EN 50126-1
FTA	Fault tree analysis	EN 50126-1
RAMS	Reliability, availability, maintainability and safety	EN 50126-1
RCM	Reliability centred maintenance	IEC 60300-3-11
MTTR	Mean time to repair	EN 13306
MTTM	Mean time to maintain	
PDM	Predetermined maintenance. Preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation Note 1: to entry: Intervals of times or number of units of use may be established from knowledge of the failure mechanisms of the item.	EN 13306
CBM	Condition based maintenance. Preventive maintenance which include assessment of physical conditions, analysis and the possible ensuing maintenance actions Note: 1 to entry: The condition assessment may be by operator observation, and/or inspection, and/or testing, and/or condition monitoring of system parameters, etc., conducted according to a schedule, on request or continuously.	EN 13306
MP	Maintenance program (plan); structured and documented set of tasks that include the activities, procedures, resources, and the time scale required to carry out maintenance	EN 13306
Preventive maintenance	Maintenance carried out intended to assess and/or to mitigate degradation and reduce the probability of failure of an item	EN 13306
Active preventive maintenance	Active preventive maintenance is the part of preventive maintenance where actions are undertaken to restore an item directly or subsequent to degradations observed through condition monitoring, inspection or testing.	EN 13306

2. Maintenance concept

All new rolling stock for Norske tog is to be supplied with a fully developed maintenance program, maintenance instructions and schedule of intervals based on RCM analysis. The RCM analysis shall be based on an approach according to a recognized standard, e.g. IEC 60300-3-11, S4000P or equivalent.

If the Contractor has an internally developed RCM methodology the method approach to RCM shall be discussed and agreed upon between the Contractor and Norske tog. The result of the RCM analysis shall be outlined in a report and included in a maintenance program. The maintenance program is a specification based on the results of the RCM analysis and includes all RCM analysis decisions. Decisions resulting in maintenance tasks shall be the basis for developing a maintenance plan. The maintenance program shall also indicate relevant KPI’s, based on decision uncertainties identified in the RCM analysis workshops.

The RCM analysis results shall define safety related maintenance activities identified in the risk analysis.

The RCM analysis results shall identify maintenance activities which are required to prevent any impact in the operation resulting in cancellations, delays or customers satisfaction.

The RCM analysis results shall include a corrosion prevention and control program (CPCP).

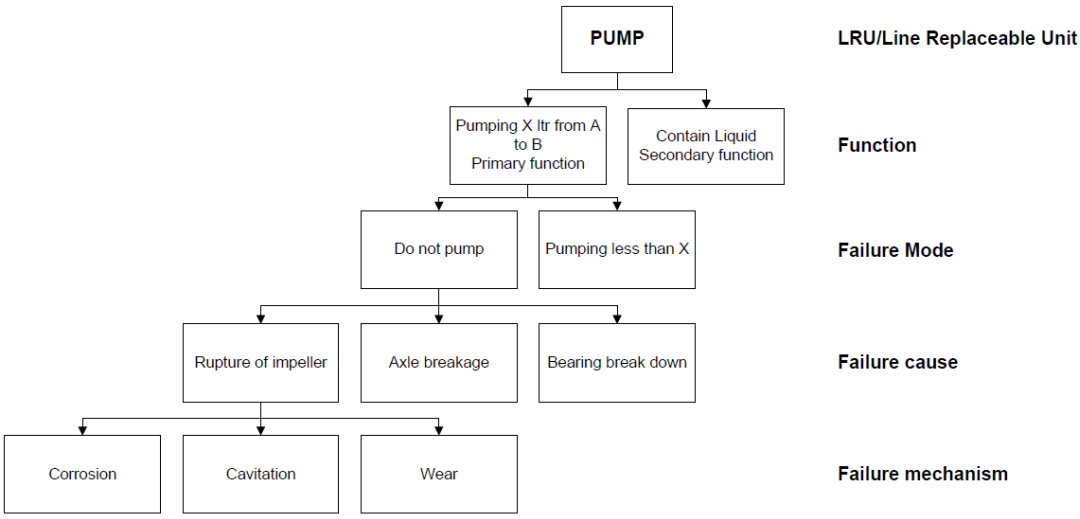
The RCM analysis report and related maintenance documentation shall comply with the NRA vehicle regulation (Kjøretøyforskriften), appendix 1 paragraph 1.2.1/1.2.2 and TSI LOC & PAS 4.2.12.3/ TSI LOC & PAS 4.2.12.3.1, maintenance documentation and maintenance design justification file.

3. Failure mode and effect analysis, FMEA

FMEA as a basis for the RCM analysis shall be based on the level definitions outlined in figure 4.1. These definitions are essential to continue and succeed with the RCM analysis. The FMEA should be detailed to an LRU level.

4. Base Order (TSSSA)

The Base Order is the main scope of supply. The basic set-up is that the Operators conducts all maintenance on the Trainsets, except specified activities which are conducted by the Contractor. The main task for the Contractor is to ensure that all the correct support in conducting maintenance by the Operators are at place when needed during the entire Lifetime.



LRU/Line Replaceable Unit:	PUMP
Primary function:	Pumping X litres/h from A to B.
Secondary function:	Containment of liquid
Failure mode:	Pumping less than X litres/h or do not pump
Failure cause:	Rupture of impeller, bearing break down or axle breakage
Failure mechanism:	Corrosion, wear, cavitation

Figure 5.1 Definitions of the levels in the “failure hierarchy”

Failure mechanisms may have different behaviour and patterns. Fig. 5.2 illustrates behaviour of typical failure mechanisms.

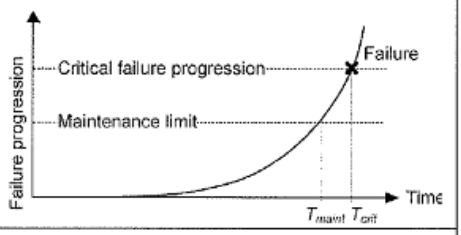
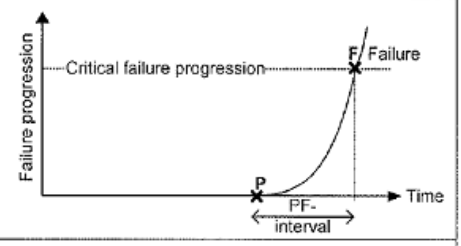
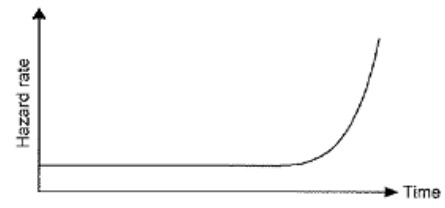
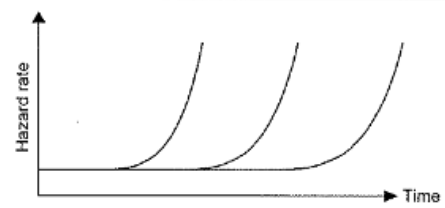
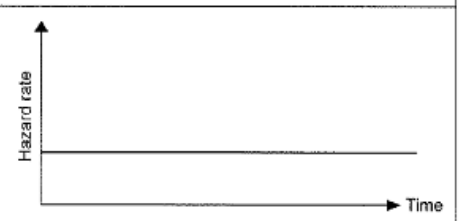
Code	Description	Failure characteristic
OGF	Observable, gradual failure development. It is possible to detect the failure prior to failure.	
OFF	Observable fast failure progression. The Point P is the first point in time where it is possible to reveal an emerging failure. When the failure progression exceeds a limiting value, a failure (F) occurs.	
ADT	Aging, defined point of time for an increasing hazard rate. (Aging parameter in the order 3 to 4)	
AUT	Aging, undefined point of time for increasing hazard rate. (Aging parameter in the order 2)	
RF	The hazard rate is time independent (random failures, aging parameter 1). This is typical for components where a failure is caused by external shocks, e.g., for some electrical components.	

Fig. 5.2 Typical failure characteristics

If the FMEA analysis is typically performed by the sub-suppliers, the FMEA requirements shall be detailed in the agreement with sub-suppliers to ensure that the analysis and results is in line with the RCM methodology and can be assembled correctly and effectively in the RCM analysis. The RCM analysis shall be performed by the supplier projecting and assembling the rolling stock. The sub-supplier should be required to follow specific definitions as shown above. In addition to traditional failure data as failure rate and MTBF, the sub-supplier should be contracted to deliver the level with failure characteristics as the main basis of succeeding with Condition-Based Maintenance strategy including condition monitoring. The sub-supplier shall only deliver defined failure effects within the functional boundary of the delivery, meaning “local” effects. The so-called global effect should be defined by the supplier performing the RCM analysis. This is the part of the RCM which is the functional failure analysis. This is covered by /5/ IEC 60300-3-11 chapter 5.1.3 and /4/ S4000P chapter 2.4.

This document is guidelines to establish an effective RCM analysis method and approach adapted to the project and the purpose of the analysis. It is recommended that the RCM analysis process is included and integrated in the design phase to be a consistent tool in engineering and design to obtain the most effective maintainability, maintenance program (CBM strategy) and finally contribute to achieving the availability target at a minimum maintenance cost.

5. Maintenance types definitions and descriptions

Maintenance overall types should be defined for the maintenance program as Predetermined Maintenance, PDM, and Condition-Based Maintenance, CBM. The maintenance program shall be developed with emphasis on CBM as the preferred maintenance type. The overall types are defined;

The maintenance plan is a structured and documented set of tasks that include the activities, procedures, resources and the time scale required to carry out maintenance.

The maintenance type Predetermined Maintenance (PDM) is servicing, restoration or discards tasks performed on equipment based on a calendar or fixed time/km schedule.

The maintenance type Condition-Based Maintenance (CBM) is means of stating the condition of systems and equipment which calls for maintenance when need arises. The maintenance task definitions in the RCM are based on using inspection techniques, condition monitoring or real-time data to state the condition and call for maintenance as needed. The intention of the CBM is to plan, prioritize and optimize maintenance resources.

When the decision in the RCM analysis is “no task” the following codes shall be used as applicable in the task code field:

AAPM Activity after preventive maintenance

PCM Planned corrective maintenance

The following task definitions shall be used for decision of maintenance type CBM in the RCM analysis and the maintenance program;

VIS - Visual Inspection

FTE - Functional Test

ADJ – Adjustment

MEA - Measurement

The following task definitions shall be used for decision of maintenance type PDM in the RCM analysis and the maintenance program;

LUB - Lubrication

CLE - Cleaning

RPL – Replacement

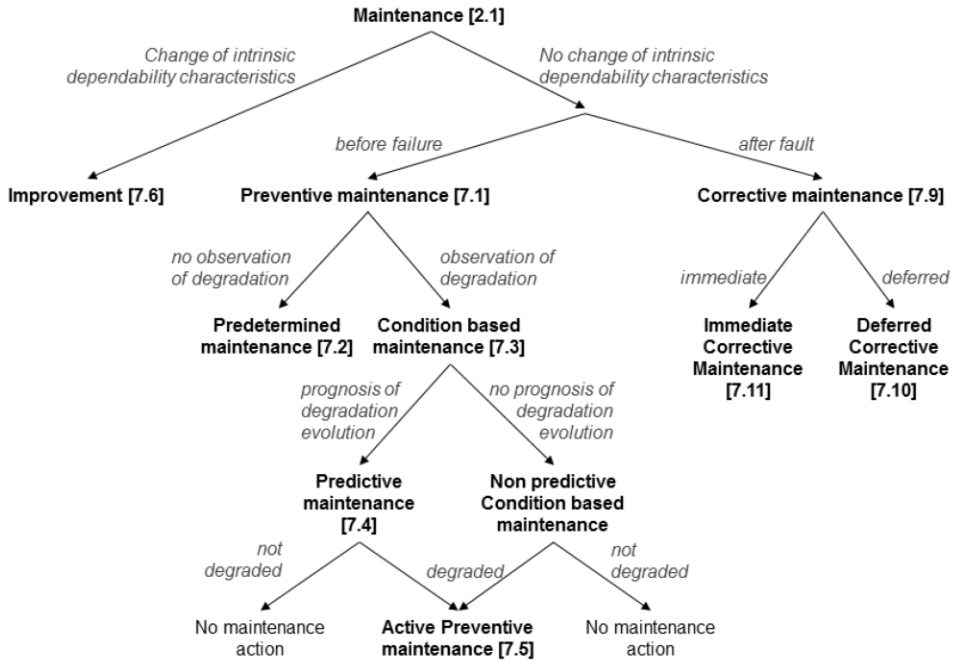


Figure 4.1 Maintenance types ref. EN 13306

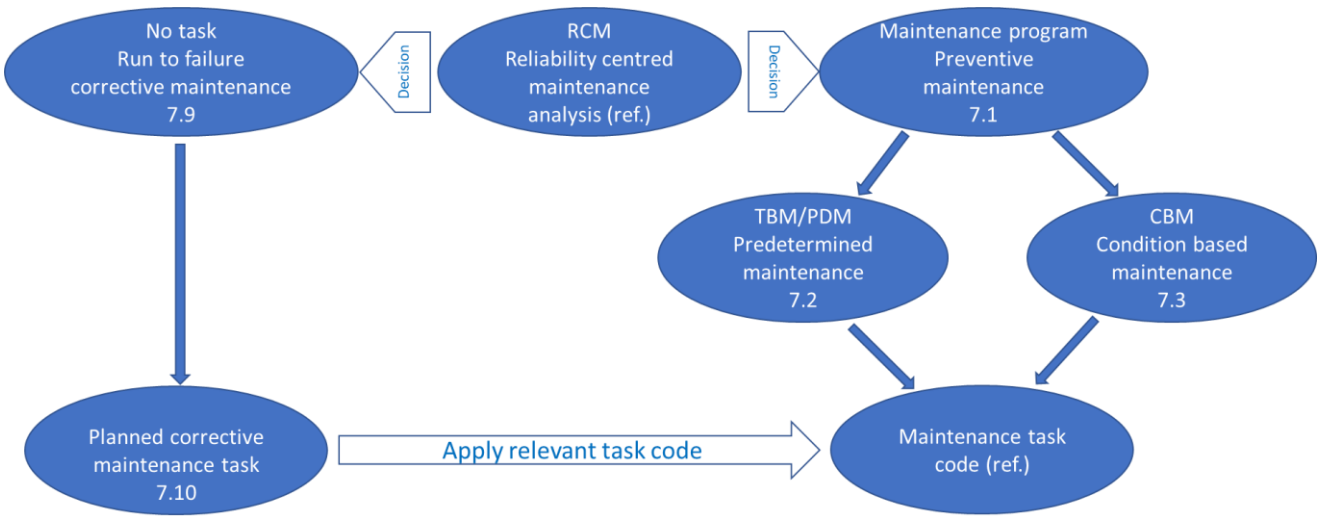


Figure 4.2 Application of EN 13306

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6. CBM task types (predictive and non-predictive)

Inspection/monitoring tasks have different defined practices within the area of visual inspection, VIS. The practice includes general visual inspection, detailed visual inspection, non-destructive inspection and scheduled condition monitoring. Continuous condition monitoring will not generate a task in the maintenance plan since the need for corrective maintenance is alerted to the on-board personnel or the maintenance crew directly for planning and execution of corrective maintenance. Functional test, FTE, has two main practices, operational check which is general and functional check which is detailed with specific defined measures. Test adjustment includes calibration, sampling, etc. The task decision shall be outlined in the RCM analysis, be included in the maintenance program and be traceable to the maintenance and operation documentation. The RCM analysis shall include the following task types and practice for the CBM strategy. The tasks shall be coded accordingly.

6.1 Visual inspection (VIS)

Visual inspection includes different practices and use different aids for the inspections. The first sentence in the task shall start with the practice descriptions as shown below;
Standard Norwegian translation: Visuell inspeksjon (VIS)

6.2 General Visual Inspection

The inspection is general for an area or assembly and does not specify specific objects and inspection criteria, such as measurements etc. The task should not include disassembly of parts to uncover inspection areas. The distance to the objects is not less than an arm's length if not otherwise specified. Good light conditions, flashlight as necessary. Move, shake, pull, twist and push parts when possible. Be aware of other systems in the inspection area. Look for abnormalities. View inspection items from different angles if possible. Inspect all structural components, all movable parts, all attach points and brackets. Check all cables, conduits and hoses for condition and clearance. Check condition and security of load and stress points. Look for chafing and fretting corrosion. Observe proximity of components. Look for loose and missing fasteners, noticeable cracks, indications of corrosion and debris in closed areas. Observe that cables, conduits and hoses are properly routed and released for strain.

6.3 Detailed Visual Inspection

A detailed visual inspection is an intensive visual examination of a specific assembly or part to detect expected failures or irregularities. Inspection aids may be required, such as mirror, supplemental lightening, magnifying glass, dye-penetrant, boroscope, and specialized hand tools as calibrated measurement tools. Surface preparation, cleaning and elaborate access may be required. Detailed documentation required is specific to the inspection procedure outlined step by step on work cards as well as reporting procedure. A DVI shall have specified inspection tolerance limits. The reason for the inspection should be specified for the maintainer as well as expected failures. The results shall be recorded.

6.4 Non-destructive Inspection

An NDI is specified if an early detection of a failure development is necessary to establish an effective inspection interval meaning that the P-F interval is too short to be controlled by a DVI. An NDI may also be specified if an inspection area is not accessible, for example inside closed vessels. NDI inspections are performed as a procedure step by step and with specified special NDI equipment as ultrasonic, eddy-current, X-rays, magnaflux, etc. An NDI shall have specified inspection tolerance limits. The reason for the inspection should be specified for the maintainer as well as expected failures. The results shall be recorded.

6.5 Scheduled Condition Monitoring

Scheduled monitoring is an examination of equipment or systems condition which cannot be performed as a DVI. SCM is a scheduled monitoring of different energy levels in systems or equipment like temperatures, pressure, vibration, etc. An SCM is always performed with the technical system running in normal operation with specified sensor equipment. An SCM task is typically specified if continuous monitoring is not practicable or not cost efficient. An SCM shall have specified tolerance limits. The reason for the inspection should be specified as well as expected failures. The results shall be recorded.

6.6 Online Condition Monitoring
Online condition monitoring means that the vehicle on-board computer (VCU) is transmitting failure data to the landside maintenance control center, and the maintenance will be planned and ordered from there. The monitoring may apply for electric/electronic systems with random failure distribution.

6.7 Operational Check
An operational check is specified when there is a need on a scheduled basis to ensure if equipment is operative as intended when needed. Does not require quantitative tolerances. An OPC is normally called out on equipment that is normally not operative. For example, manually operated service valves which are normally closed or open (isolating valves), emergency exit doors which is normally not in use, etc. are typical objects for OPC. The procedure is to operate the equipment as the intended use, e.g. open/close door, valve, etc.

6.8 Adjustment (ADJ)
Adjustment is the activity of checking, by comparison with a standard or instrument, the accuracy of a component function including adjustment of the component function to bring it into alignment with the standard. For example, the set point of a relief valve. Detailed documentation required is specific to the test procedure outlined step by step as well as reporting procedure.
Standard Norwegian translation: Justering (JUS)

6.9 Sampling
Sampling (SMP) is a method to test the general health of components. Samples are normally liquid and analysed to find evidence of abnormal wear and deterioration. Sampling is a form of tool to monitor condition. For example, oil sample from a gearbox to reveal the composition of any metal particles suspended in the oil to evidence abnormal wear. An SMP shall have specified tolerance limits to initiate service or overhaul of the component.

6.10 Functional Test (FTE)
A detailed visual inspection is an intensive visual examination of a specific assembly or part to detect expected failures or irregularities. Inspection aids may be required, such as mirror, supplemental lightening, magnifying glass, dye-penetrant, boroscope, and specialized hand tools as calibrated measurement tools. Surface preparation, cleaning and elaborate access may be required. Detailed documentation required is specific to the inspection procedure outlined step by step on work cards as well as reporting procedure. A DVI shall have specified inspection tolerance limits. The reason for the inspection should be specified for the maintainer as well as expected failures. The results shall be recorded.

7. PDM task types

Predetermined maintenance is specific maintenance actions other than stating a condition which includes fixed intervals for component replacements, generally a specific servicing and scheduled lubrication. The task decision shall be outlined in the RCM analysis, included in the maintenance program and be traceable in the maintenance and operation documentation. The RCM analysis shall include the following task types and definitions for the PDM strategy. The tasks shall be coded accordingly.

7.1 Lubrication (LUB)
Lubrication is a task for the purpose of maintaining the components inherent design capabilities. The task is normally performed according to the Contractor's recommendations. Lubrication is performed to ensure the components predicted life. A LUB task is not a task to reveal failures or deterioration in components or systems.
Standard Norwegian translation: Smøring (SMØ)

7.2 Cleaning (CLE)

Cleaning tasks is a part of good maintenance practice. Cleaning may avoid external influence on equipment which may lead to different failure developments as corrosion, wear and tear, etc. Cleanliness will also maintain proper detectability for visual inspections. A CLE task is not a task to reveal failures or deterioration in components or systems.
Standard Norwegian translation: Rengjør (REN)

7.3 Replacement (RPL)

Replacement task consists of two types of tasks. Discard and Overhaul:

Discard task is the removal from service of an item at a specified predetermined life limit. The item is not reused but replaced by a new item. A DIS task is not a task to reveal failures or deterioration in components or systems in the 1st line maintenance.

Overhaul or restoration is work necessary to ensure or return an item to a specific standard. Overhaul as a task in the maintenance program means that the task interval is time specific and the item removed from the vehicle (1st line maintenance) for overhaul (2nd line maintenance) at a predetermined interval. Overhaul is a 2nd line maintenance activity and performed to restore the item to ensure predicted lifetime. OVH task is not a task to reveal failures or deterioration in components or systems in the 1st line maintenance.
Standard Norwegian translation: Bytt (BYT)

7.4 Measurement (MEA)

Measurement task is the measure of an item at a specified predetermined life limit. The item may be reused if the measure result is within predetermined tolerance thresholds. If the measure result is outside the tolerance threshold, the item shall be replaced by a new item. MEA task is a task to reveal failures or deterioration in components or systems in the 1st line maintenance.
Standard Norwegian translation: Mål (MÅL)

7.5 Calibrate (CAL)

Calibrate task is the calibration to the correct value of an item at a specified predetermined life limit. The item is reused after calibration. The CAL task is not a task to reveal failures or deterioration in components or systems in the 1st line maintenance.
Standard Norwegian translation: Kalibrer (KAL)

8. PDM task types

If the decision in the RCM analysis is no maintenance task for the maintenance plan, e.g. “run to failure” decision or online monitoring, the task code shall be noted in the appropriate field in the RCM sheet with one of the following codes;

8.1 Planned corrective maintenance (PCM)

Planned corrective means that the decision in the RCM is no task and the expected corrective maintenance will be performed at the expected failure rate. This value should be given in the RCM and will be the same as from the LCC calculations.

8.2 AAPM

Activity after preventive maintenance (AAPM) means a corrective action from an expected failure finding from a preventive task, e.g. CBM task.

9. PDM task types

The RCM analysis shall have a special focus on CBM (Condition-Based Maintenance) in the process of developing the planned maintenance program. The contractor shall describe the RCM analysis approach to develop a consistent maintenance program with focus on CBM tasks. Continuous condition monitoring, CCM, defined in the RCM analysis shall be included in a monitoring program for planned corrective maintenance included in the analysis and maintenance program defined as a PCM.

10. PDM task types

The vehicle on-board systems diagnostics shall be actively used to improve the CBM strategy in the maintenance program. The arrangement and coding of information shall be in line with the RCM analysis. E.g. level 0 maintenance tasks shall be available for the driver in the display unit during operation. Level 1 maintenance shall be available for the maintenance organisation online or regular downloads.