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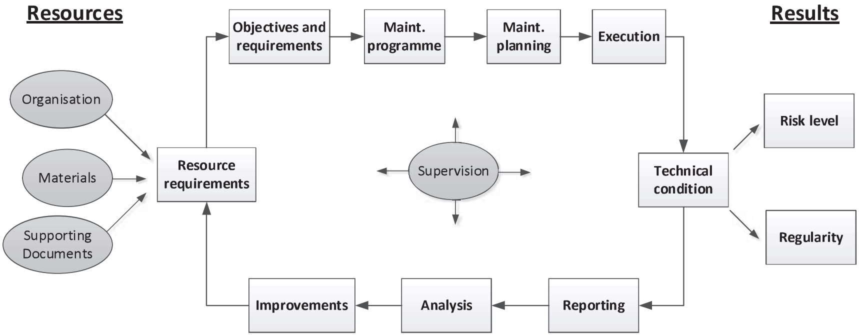
MAINTENANCE MANAGEMENT AND RELIABILITY CENTRED MAINTENANCE

Jørn Vatn/February-2024

Maintenance management

- **Definition:** All activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics
- In particular:
  - Planning, scheduling, and managing maintenance for parts, vehicles, and other essential equipment
  - Predicting potential issues and scheduling regular maintenance tasks to eliminate them
  - With more real-time data, it is possible to streamline the maintenance process and make it more cost-effective
- An important aspect of maintenance management is to understand the maintenance management loop:

Maintenance management loop NORSOK-Z008/HAVTIL



Objectives and requirements

- No accidents, follow safety regulations, ...
- High availability and regularity
- Optimal use of resources, i.e., maintenance optimization

Maintenance programme

- How to come up with a reasonable maintenance program?
- Reliability centred maintenance - RCM

What is RCM?

- RCM is a method for maintenance planning developed in the sixties within the aircraft industry and later adapted to several other industries and military branches
- A major advantage of the RCM analysis process is a structured, and traceable approach to determine the optimal type of preventive maintenance (PM)
- The main focus is on preventive strategies, but the results from the analysis may also be used in relation to corrective maintenance strategies, spare part optimization, and logistic considerations

The seven main questions in RCM

1. What are the system functions and the associated performance standards?
2. How can the system fail to fulfil these functions?
3. What can cause a functional failure?
4. What happens when a failure occurs?
5. What might the consequence be when the failure occurs?
6. What can be done to detect and prevent the failure?
7. What should be done when a suitable preventive task cannot be found?

The main objectives of an RCM analysis process are to:

- Identify effective maintenance tasks
- Evaluate these tasks by some cost–benefit analysis
- Prepare a plan for carrying out the identified maintenance tasks at optimal intervals

Steps involved in an RCM analysis

1. Study preparation
2. System selection and definition
3. Functional failure analysis (FFA)
4. Critical item selection
5. Data collection and analysis
6. Failure modes, effects, and criticality analysis (FMECA)
7. Selection of maintenance actions
8. Determination of maintenance intervals
9. Preventive maintenance comparison analysis
10. Treatment of non–critical items
11. Implementation
12. In–service data collection and updating

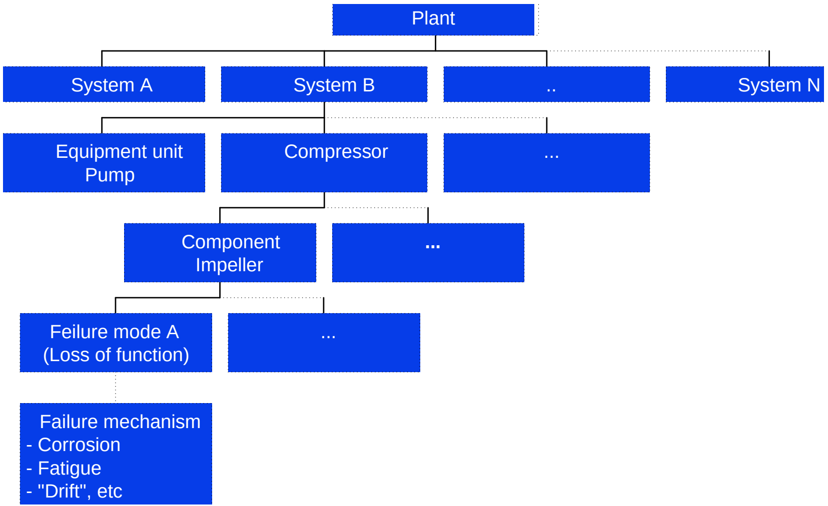
Step 1: Study preparation

- Before the actual RCM analysis process is initiated, an RCM project group must be established
  - The group should include at least one person from the maintenance function and one from the operations function, in addition to an RCM specialist.
- Define consequences to be evaluated, e.g.:
  - Human injuries and/or fatalities
  - Negative health effects
  - Environmental damage
  - Loss of system effectiveness (e.g., delays, production loss)
  - Material loss or equipment damage
  - Loss of marked shares

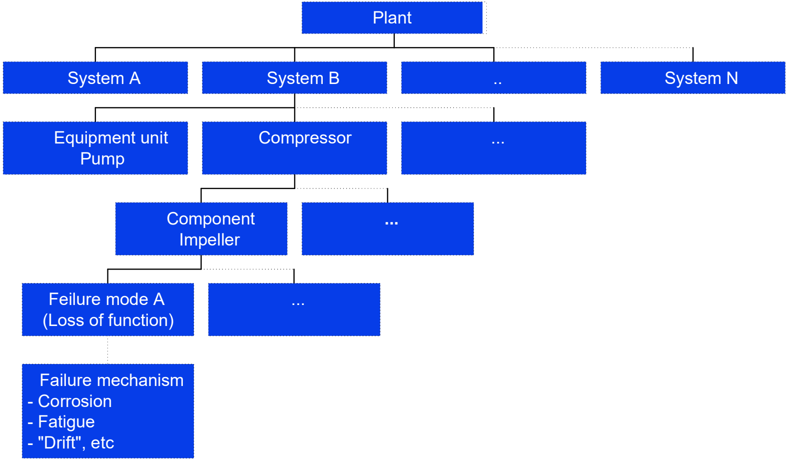
Step 2: System selection and definition

- Before a decision to perform an RCM analysis is taken, two questions should be considered:
  - To which systems are an RCM analysis beneficial compared with more traditional maintenance planning?
  - At what level of assembly (plant, system, subsystem) should the analysis be conducted?

System hierarchy



RCM approach



One system is chosen at a time

Analysis item

Failure mechanism and failure causes could be mitigated, i.e. maintenance

Step 3: Functional failure analysis (FFA)

- The objectives of this step are to
  1. Identify and describe the systems' required functions
  2. Describe input interfaces required for the system to operate
  3. Identify the ways in which the system might fail to function

System: Pitch system
Ref. drawing no.: X-Y-Z-1-2-3

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Opera-tional mode	Function	Function requirements	Functional failure	Freq-uency	Criticality			
					S	E	A	C
Turbine is running	Increase pitch angle	+/- 1°	Pitch angle can not be changed	1 per year	Med-ium	No impact	High	Med-ium

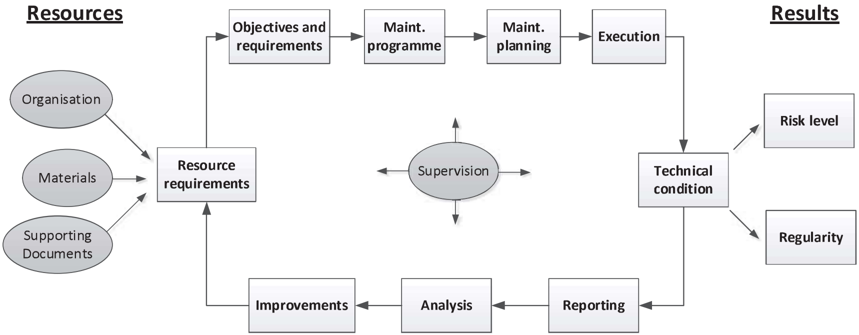
Step 4: Critical item selection

- Identify the analysis *items* that are potentially critical with respect to the functional failures identified in Step 3 $\Longrightarrow$ FSI = Functional Significant Items
- In addition to the FSIs, we should also identify items with high failure rate, high repair costs, low maintainability, long lead-time for spare parts, or items requiring external maintenance personnel $\Longrightarrow$ MCSI = Maintenance Cost Significant Items
- MSI = Maintenance Significant Items = FSIs $\cup$ MCSIs

Step 5: Data collection and analysis

- Establish a basis for both the qualitative analysis (relevant failure modes and failure causes), and the quantitative analysis
- The data necessary for the RCM analysis may be categorized in the following three groups:
  1. Design data (Equipment type, capacities etc.)
  2. Operational and failure data (operating # of hours, failure times etc)
  3. Reliability data (MTTF, aging parameters etc.)
- Step 5 is important both as a starting point for the RCM, but also to "close" the *maintenance management loop*

Maintenance management loop NORSOK-Z008/HAVTIL

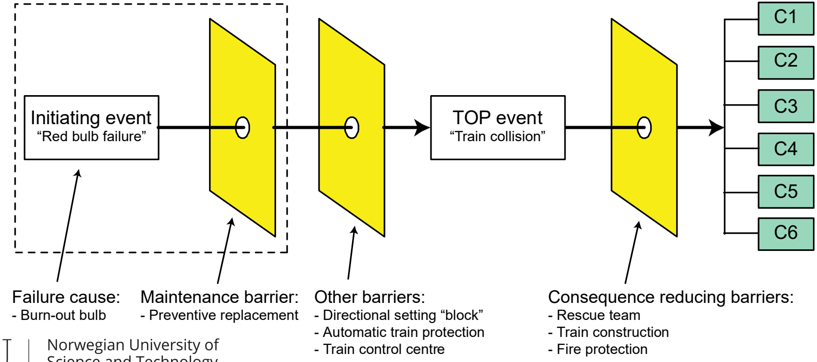


Step 6: FMECA - Failure mode, effect and criticality analysis

- Identify the dominant failure modes of the MSIs identified in Step 4
- The information entered into the FMECA worksheet should be sufficient both with respect to maintenance task selection in Step 7, and interval optimization in Step 8
- The FMECA is used as the *main database* for the RCM analysis
- The FMECA is essential conducted as a worksheet exercises, where the columns should reflect the needs for subsequent steps

Barrier model for safety and other dimensions

- Experience has shown that a logical barrier model as a basis will ease the structuring of information going into the FMEA:
- In particular the oil&gas industry and the railway industry have a barrier management focus



FMECA example: Red light bulb

- Component
  - Red light bulb, main signal
- Functions
  - Give the engine driver a signal to ”STOP”
  - Enabling the possibility to allow green light from the other direction
- Failure mode
  - No light from the light bulb
- Failure causes
  - Burnt-out filament, short circuit, wire failure, lamp socket
- Failure effects
  - Safety: May lead to collision train-train
  - Punctuality: Not able to set green light from the other side, delays

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Example of a part of an FMECA worksheet

System function: Ensure correct departure light signal
Functional failure: No signal

MSI	Function	Failure mode	Failure cause	TOP event Safety	Safety barriers	$P_{TE\text{-}S}$	TOP event Punct.
Lamp	Give light	No light	Burnt-out filament	Train - Train	Directional block, ATP, TCC, “Black=red”	$3 \cdot 10^{-4}$	Manual train operation
Lens	Protect lamp	Broken lens	Rock fall	Train - Train	Directional block, ATP, TCC, “Black=red”	$2 \cdot 10^{-5}$	None
	Slip through light	No light slipping through	Fouling	Train - Train	Directional block, ATP, TCC, “Black=red”	$2 \cdot 10^{-4}$	None

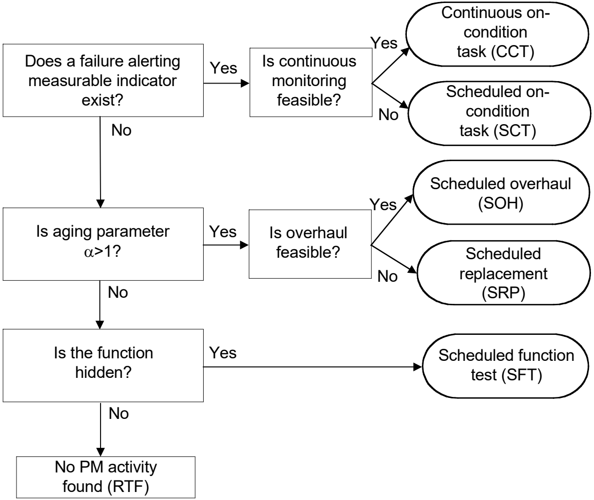
Step 7: Selection of Maintenance Actions

- A decision logic is used to guide the analyst through a question–and–answer process
- The input to the RCM decision logic is the dominant failure modes from the FMECA in Step 6
- The main idea is for each dominant failure mode to find a suitable preventive maintenance task

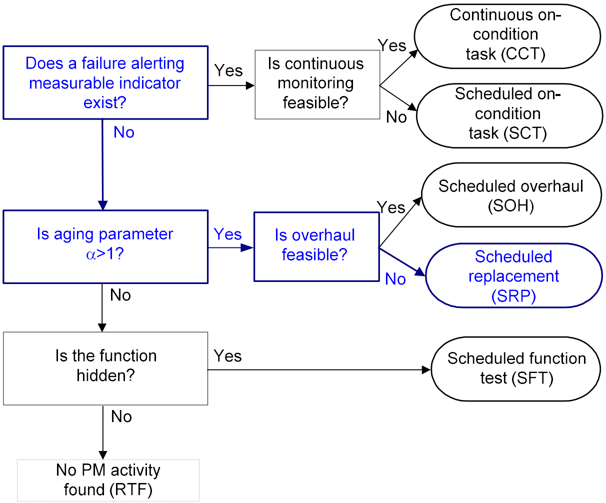
Type of maintenance tasks

- The failure mechanisms behind each of the dominant failure modes should be entered into the RCM decision logic to decide which of the following basic maintenance tasks that is most applicable:
    - Continuous on–condition task (“online condition monitoring”)
    - Scheduled on–condition task (“offline condition monitoring”)
    - Scheduled overhaul
    - Scheduled replacement
    - Scheduled function test
    - Run to failure

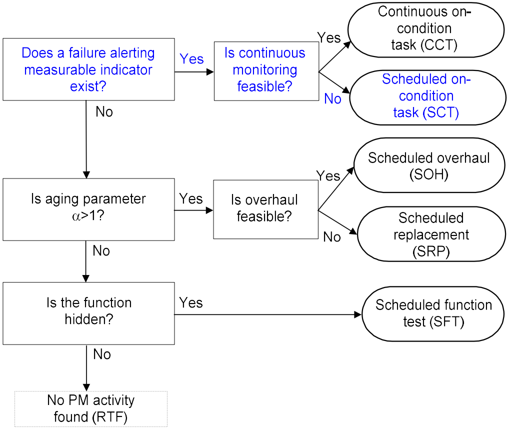
Maintenance Task Assignment/Decision logic



Red light bulb example



Matrix light bulb



Step 8: Determination of Maintenance Intervals, Timing belt example

- A timing belt is a vital component in non-electrical cars
- A failure of this component can cause a costly engine failure
- Find the optimal replacement interval if:
  - $\text{MTTF} = 175\,000$ km, i.e., if not replaced
  - Medium ageing
  - $c_{\text{PM}} = 7\,000$ NOKs
  - $c_{\text{U}} = 35\,000$ NOKs

Show solution in Excel

Objective function

- In order to find an optimal maintenance interval we need
- An objective function, i.e., a cost function to minimize
- The objective function, $C(\tau)$ comprises
  - A term describing the cost of the maintenance activity, i.e., c_{PM}/τ
  - A term describing the cost of failures, i.e., $\lambda_{\mathrm{E}}(\tau)c_{\mathrm{U}}$
  - $\lambda_{\mathrm{E}}(\tau)$ = effective failure rate
  - c_{U} = expected cost of failure (repair, downtime etc)

Optimal value of τ

- In order to derive an optimal maintenance interval we introduce a more general formula for the effective failure rate:

$$\lambda_{\mathrm{E}}(\tau) = \left(\frac{\Gamma(1 + 1/\alpha)}{\mathrm{MTTF}}\right)^{\alpha} \tau^{\alpha-1}$$

- Where the ageing parameter α is obtained by:
  - Low ageing: $\alpha = 2$
  - Medium ageing: $\alpha = 3$
  - Strong ageing: $\alpha = 4$
- $\Gamma()$ is the gamma function (e.g., `=Gamma(1+1/3)` in Excel)

Optimal value of τ

By equating the derivative of the cost equation (objective function) to zero, we find the optimal interval:

$$
\begin{aligned}
C(\tau) &= c_{\mathrm{PM}}/\tau + \lambda_{\mathrm{E}}(\tau) c_{\mathrm{U}} \\
C(\tau) &= c_{\mathrm{PM}}/\tau + \left(\frac{\Gamma(1+1/\alpha)}{\mathrm{MTTF}}\right)^{\alpha} \tau^{\alpha-1} c_{\mathrm{U}} \\
C'(\tau) &= -c_{\mathrm{PM}}/\tau^2 + \left(\frac{\Gamma(1+1/\alpha)}{\mathrm{MTTF}}\right)^{\alpha} (\alpha-1)\tau^{\alpha-2} c_{\mathrm{U}} = 0 \implies \\
\tau^* &= \frac{\mathrm{MTTF}}{\Gamma(1+1/\alpha)} \left(\frac{c_{\mathrm{PM}}}{c_{\mathrm{U}}(\alpha-1)}\right)^{1/\alpha}
\end{aligned}
$$

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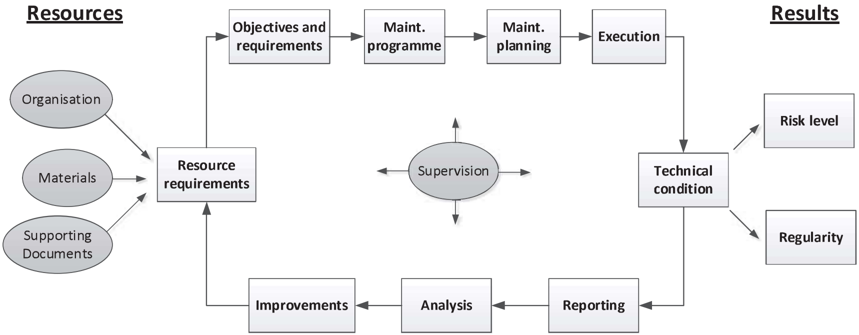
Maintenance management loop



Thank you for your attention

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