Chapter 9
Reliability Centered Maintenance

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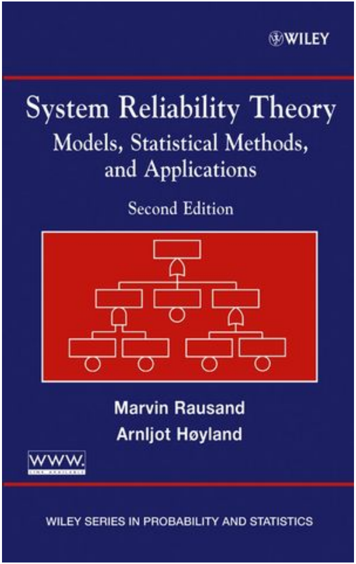
Slides related to the book

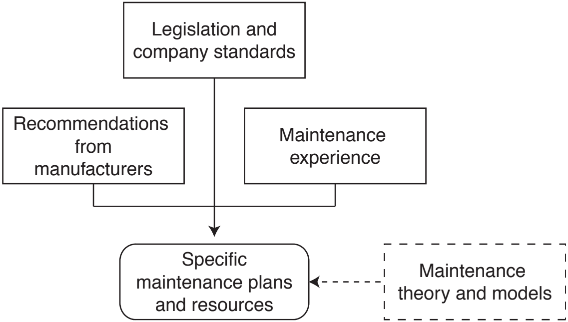
System Reliability Theory
Models, Statistical Methods,
and Applications

Wiley, 2004

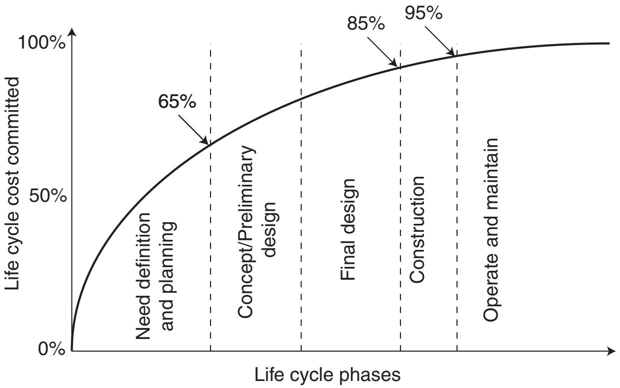
Homepage of the book:
http://www.ntnu.edu/ross/books/srt



Maintenance strategy development



Life cycle cost commitment



Source: Blanchard, B.S., Design and Manage to Life Cycle Cost, Forest Grove, OR, MA Press, 1978

Reliability-centered maintenance

☞ Reliability-centered maintenance (RCM): A systematic consideration of system functions, the way functions can fail, and a priority-based consideration of safety and economics that identifies applicable and effective PM tasks. [EPRI]

Objective: To reduce the maintenance cost, by focusing on the most important functions of the system, and avoiding or removing maintenance actions that are not strictly necessary

RCM is not a substitute for poor design, inadequate build quality or bad maintenance practices.

RCM literature

- Nowlan, F. S. and H. Heap (1978): “Reliability Centered Maintenance”
- IEC 60300-3-11 (1999): “Dependability management - Application guide: Reliability centered maintenance”
- NASA (2000): “Reliability Centered Maintenance Guide for Facilities and Collateral Equipment”
- MIL-STD 2173(AS), “Reliability-Centered Maintenance. Requirements for Naval Aircraft, Weapon Systems and Support Equipment”
- NAVAIR 00-25-403 (1996): “Guidelines for Naval Aviation Reliability Centered Maintenance Process”
- Moubray, J. (1991): “Reliability Centred Maintenance” (Butterworth-Heinemann)
- Smith, A. M. (1993): “Reliability Centered Maintenance” (McGraw-Hill)

RCM experience

A wide range of companies have reported success by using RCM, that is, cost reductions while maintaining or improving operations regularity.

- Aircraft industry. RCM is more or less identical to MSG-3, and is standard procedure for development of new commercial aircrafts
- Military forces (especially in the US)
- Nuclear power stations (especially in the US and in France)
- Oil companies. Most of the oil companies in the North Sea are using RCM
- Commercial shipping (the first steps have been taken)

RCM basic questions

1. What are the functions and associated performance standards of the equipment in its present operating context?
2. In what ways can it fail to fulfill its functions?
3. What is the cause of each functional failure?
4. What happens when each failure occurs?
5. In what way does each failure matter?
6. What can be done to prevent each failure?
7. What should be done if a suitable preventive task cannot be found?

RCM main steps of analysis

1. Study preparation
2. System selection and definition
3. Functional failure analysis (FFA)
4. Critical item selection
5. FMECA
6. Selection of maintenance actions
7. Determination of maintenance intervals
8. Preventive maintenance comparison analysis
9. Treatment of noncritical items
10. Implementation
11. In-service data collection and updating

Study preparation

- Form RCM project group
- Define and clarify objectives and scope of work
- Identify requirements, policies, and acceptance criteria
- Provide drawings and process diagrams
- Check discrepancies between as-built documentation and the real plant
- Define limitations for the analysis

System selection

Should consider:

- 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?

The following system hierarchy levels are used:

1. Plant (e.g., process plant)
2. System (e.g., gas compression system)
3. Subsystem (e.g., one gas compressor)
4. Maintainable item (is an item that is able to perform at least one significant function as a stand alone item (e.g., pumps, valves, electric motors)

Functional failure analysis - 1

System: Performed by:
Drawing no.: Date: Page: of

Operational mode	System function	Functional requirements	Functional failure	Criticality				Frequency
				S	E	A	C	

Objectives:

- Identify and describe the system's required functions and performance criteria
- Describe input interfaces required for the system to operate
- Identify the ways in which the system might fail to function

Functional failure analysis - 2

The criticality of functional failures must be judged on plant level and should be ranked in the fours consequence classes:

S: Safety of personnel
E: Environmental impact
A: Production availability
M: Material loss

The consequence may be ranked as high (**H**), medium (**M**), low (**L**), or negligible (**N**). If at least one of the four entries are medium (M) or high (H), the functional failure should be subject to further analysis.

Critical item selection

- Functional significant items (FSI)
  FSIs are items for which a functional failure has consequences that are either medium (M) or high (H) for at least one of the four consequence classes (S, E, A, and M)
- Maintenance cost significant items (MCSI)
  MCSIs are items with high failure rate, high repair cost, low maintainability, long lead time for spare parts, or that require external maintenance personnel
- Maintenance significant items (MSI)
  MSIs are items that are either FSIs or MCSIs, or both

Data collection and analysis

Data required:

- Design data
- Operational data
- Failure mode distributions for maintainable items
- Parameters of life distributions (MTTF, failure rate functions)
- Maintainability data

RCM FMECA

System: Performed by:

Drawing no.: Date: Page: of

Description of item			Failure mode	Effect of failure								MTTF	Criti-cality	Failure cause	Failure mecha-nism	%MTTF	Failure charac-teristic	Mainte-nance action	Failure charac-teristic measure	Recom-mended interval
MSI	Operational mode	Function		Consequence class				Worst case probability												
				S	E	A	C	S	E	A	C									

Selection of maintenance actions

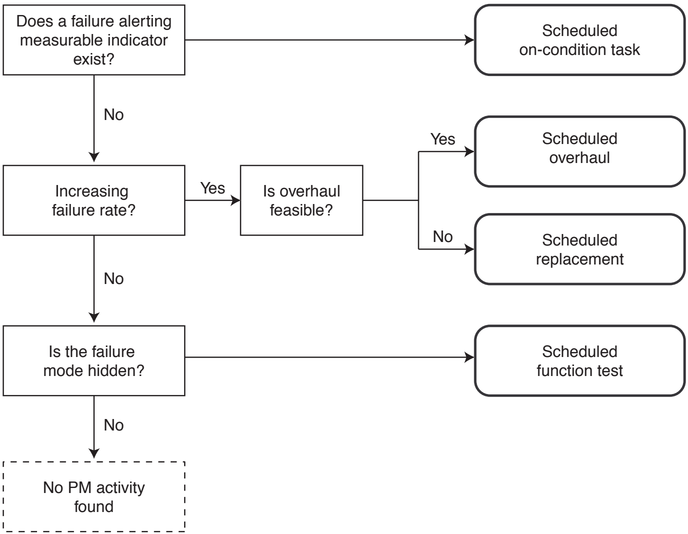
There are three main reasons for doing a PM task:

1. To prevent a failure
2. To detect the onset of a failure
3. To discover a hidden failure

The following basic maintenance tasks are considered:

1. Scheduled on-condition task
2. Scheduled overhaul
3. Scheduled replacement
4. Scheduled function test
5. Run to failure

RCM decision logic



Scheduled on-condition task

A scheduled on-condition task is carried out to determine the condition of an item, for example, by condition monitoring. There are three criteria that must be met for an on-condition task to be applicable.

1. It must be possible to detect reduced failure resistance for a specific failure mode
2. It must be possible to define a potential failure condition that can be detected by an explicit task
3. There must be a reasonable consistent age interval between the time of potential failure (P) is detected and the time of functional failure (F)

On-condition maintenance is also known as condition-based maintenance and predictive maintenance.

Scheduled overhaul - 1

Scheduled overhaul of an item may be performed at or before some specified age limit and is often called hard time maintenance. An overhaul task is considered applicable to an item only if the following criteria are met:

1. There must be an identifiable age at which there is a rapid increase in the item's failure rate function.
2. A large proportion of the items must survive to that age.
3. It must be possible to restore the original failure resistance of the item by reworking it.

Scheduled overhaul - 2

Scheduled replacement is replacement of an item (or one of its parts) at or before some specified age or time limit. A scheduled replacement task is applicable only under the following circumstances:

1. The item must be subject to a critical failure.
2. The item must be subject to a failure that has major potential consequences.
3. There must be an identifiable age at which the item shows a rapid increase in the failure rate function.
4. A large proportion of the items must survive to that age.

Scheduled function test

Scheduled function test is a scheduled failure-finding task or inspection of a hidden function to identify failures. Failure-finding tasks are preventive only in the sense that they prevent surprises by revealing failures of hidden functions. A scheduled function test task is applicable to an item under the following conditions:

1. The item must be subject to a functional failure that is not evident to the operating crew during the performance of normal duties: tasks that have to be based on information about the failure rate function, the likely consequences and costs of the failure the PM task is supposed to prevent, the cost and risk of the PM task, and so on.
2. The item must be one for which no other type of task is applicable and effective.

Run to failure

Run to failure is a deliberate decision to run to failure because the other tasks are not possible or the economics are less favorable.

Run to failure maintenance is also known as reactive maintenance, breakdown maintenance, and unscheduled maintenance.

Run to failure maintenance is generally considered to be the most expensive option, and should only be used on low-cost and easy to replace components that are not critical to operations.

Determination of maintenance intervals

Some of the PM tasks are to be performed at regular intervals. To determine the optimal interval is a very difficult task that has to be based on information about the failure rate function, the likely consequences and costs of the failure the PM task is supposed to prevent, the cost and risk of the PM task, and so on. Some models were discussed in Section 9.4.

In practice the various maintenance tasks have to be grouped into maintenance packages that are carried out at the same time, or in a specific sequence. The maintenance intervals can therefore not be optimized for each single item. The whole maintenance package has, at least to some degree, to be treated as an entity.

PM comparison analysis

Each maintenance task selected must meet two requirements:

1. It must be applicable (A PM task is applicable if it can prevent a failure, or at least reduce the probability of the occurrence of a failure to an acceptable level, or reduce the impact of a failure)
2. It must be cost-effective (i.e., the task must not cost more than the failures it is going to prevent)

Cost of a PM task

The cost of a PM task may include:

- The risk/cost related to maintenance induced failures
- The risk the maintenance personnel is exposed to during the task
- The risk of increasing the likelihood of failure of another item while the one is out of service
- The use and cost of physical resources
- The unavailability of physical resources elsewhere while in use on this task
- Production unavailability during maintenance
- Unavailability of protective functions during maintenance

Cost of a failure

The cost of a failure may include:

- The consequences of the failure should it occur (loss of production, possible violation of laws or regulations, reduction in plant or personnel safety, or damage to other equipment)
- The consequences of not performing the PM task even if a failure does not occur (e.g., loss of warranty)
- Increased premiums for emergency repairs (such as overtime, expediting costs, or high replacement power cost)

Updating process

- Short-term interval adjustments
- Medium-term task evaluation
- Long-term revision of the initial strategy

TPM - 1

Total productive maintenance (TPM) was developed in Japan (Nakajima, 1988) to support the implementation of just-in-time manufacturing and to improve product and process quality.

TPM comprises

- A philosophy to permeate throughout an operating company touching people on all levels.
- A collection of techniques and practices aimed at maximizing the effectiveness (best possible return) of business facilities and processes.

Seiichi Nakajima

TPM - 2

TPM is a Japanese approach aimed to:

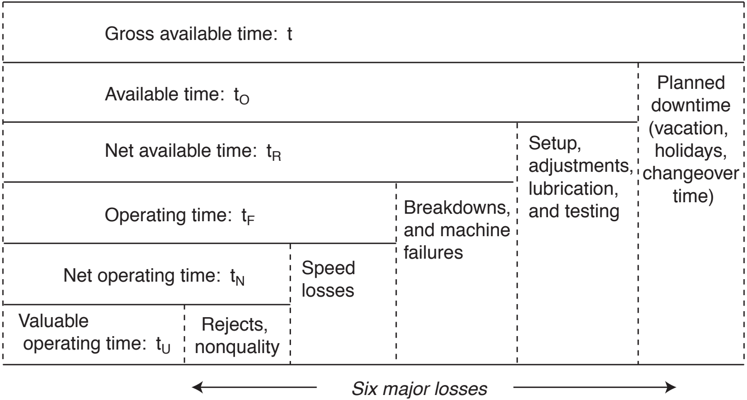
- Create a company culture that will give maximum efficiency
- Prevent losses with minimum efforts and cost
  - i.e., zero breakdowns and failures, zero accidents, and zero defects
- Create team work (small group activity) focused on condition and performance to achieve zero loss
- Involve all employees from top management to operators

Six major losses

- Availability losses
  - Equipment failure (breakdown) losses
  - Setup and adjustment losses
- Performance (speed) losses
  - Idling and minor stoppages ($\leq$ 10 minutes)
  - Reduced speed losses
- Quality losses
  - Defects is process and reworking losses
  - Yield losses

Overall equipment effectiveness - 1

The overall equipment effectiveness (OEE) is determined by the six major losses. The time concepts used are illustrated in the table below.



Overall equipment effectiveness - 2

The factors used to determine the OEE are

- Operational availability $A_{\text{O}} = t_{\text{F}} / t_{\text{R}}$
- Performance rate $R_{\text{P}} = t_{\text{N}} / t_{\text{F}}$
- Quality rate $R_{\text{Q}} = t_{\text{U}} / t_{\text{F}}$

The quality rate R_{Q} may alternatively be measured as

$$R_{\text{Q}} = \frac{\text{No. of processed products} - \text{No. of rejected products}}{\text{No. of processed products}}$$

The OEE is defined as

$$\text{OEE} = A_{\text{O}} \cdot R_{\text{P}} \cdot R_{\text{Q}}$$