Maintenance concepts

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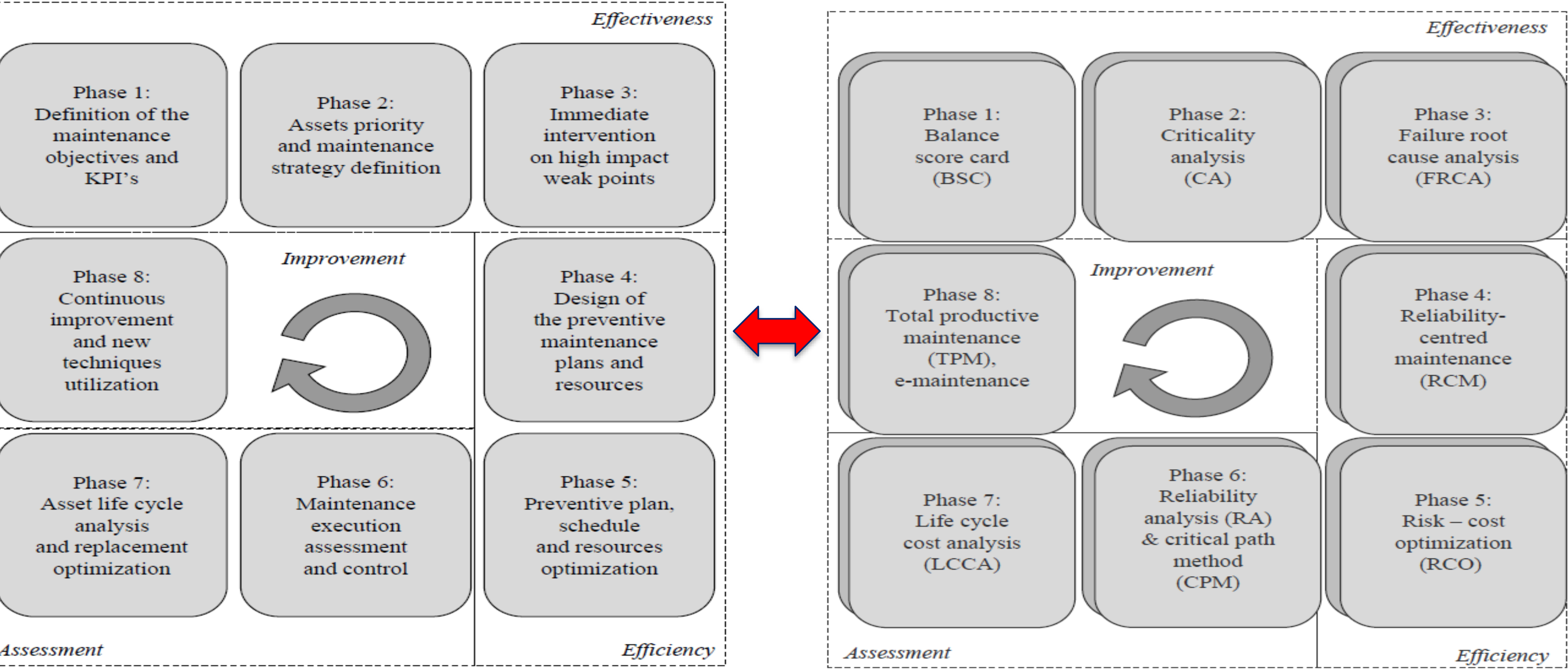
LEARNING OBJECTIVE

After this lecture, the students should be able to:

LO2: Explain, implement and distinguish various prevailing maintenance concepts

Maintenance management framework

Ma´rquez et al., (2009)



What is a maintenance concept?

- Overall model for how to plan, control, and improve maintenance
  - Basically “how to do maintenance”

- Why do we only focus on three in this course?
  - Received most attention in academia
  - Most commonly used in industry

❑ TPM = holistic model of equipment management
❑ RCM = maintenance planning method
❑ CBM = maintenance action executed based on condition

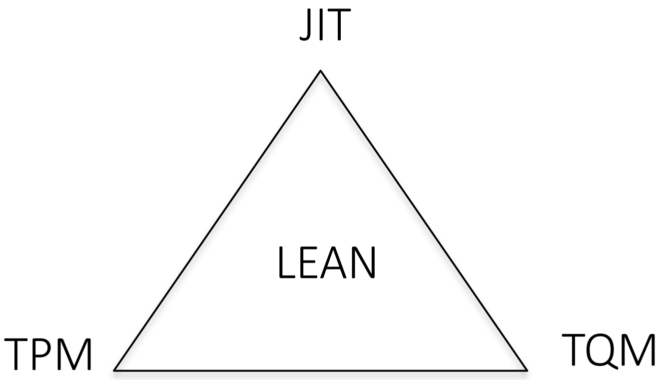
Total Productive Maintenance (TPM)

Origin? Japanese manufacturing industry

- Nippon Denso Co. Ltd, Toyota supplier, 1971
- Japanese version of US “Productive Maintenance”

Why? Support Lean Production

- Seiichi Nakajima (“father of TPM”, 1988)

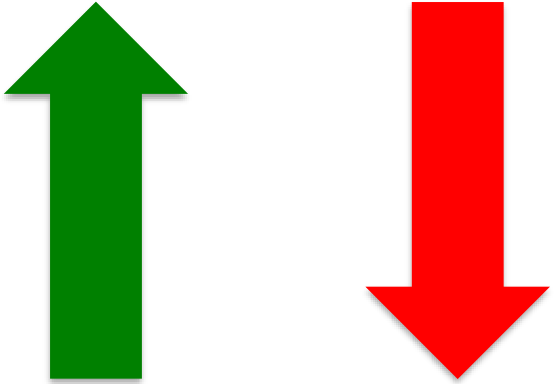


Total **Productive** Maintenance

Productive = The most economic maintenance that raises equipment productivity

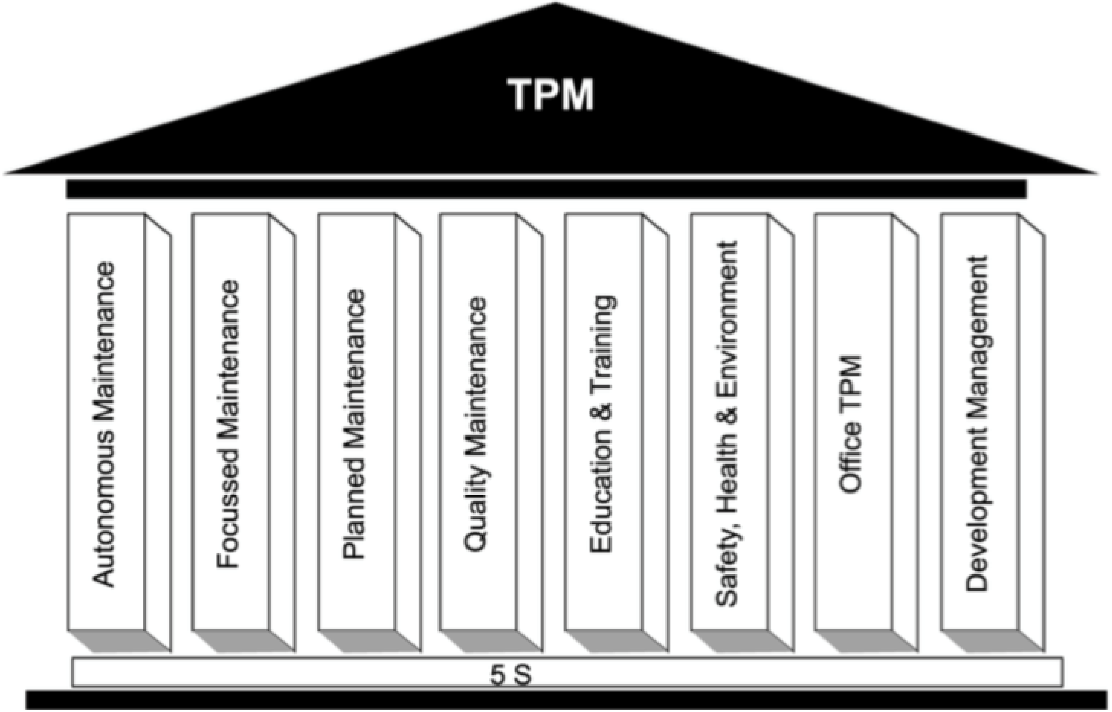
Total = the entire company is involved

Productivity



Life cycle cost

Total Productive Maintenance (TPM)

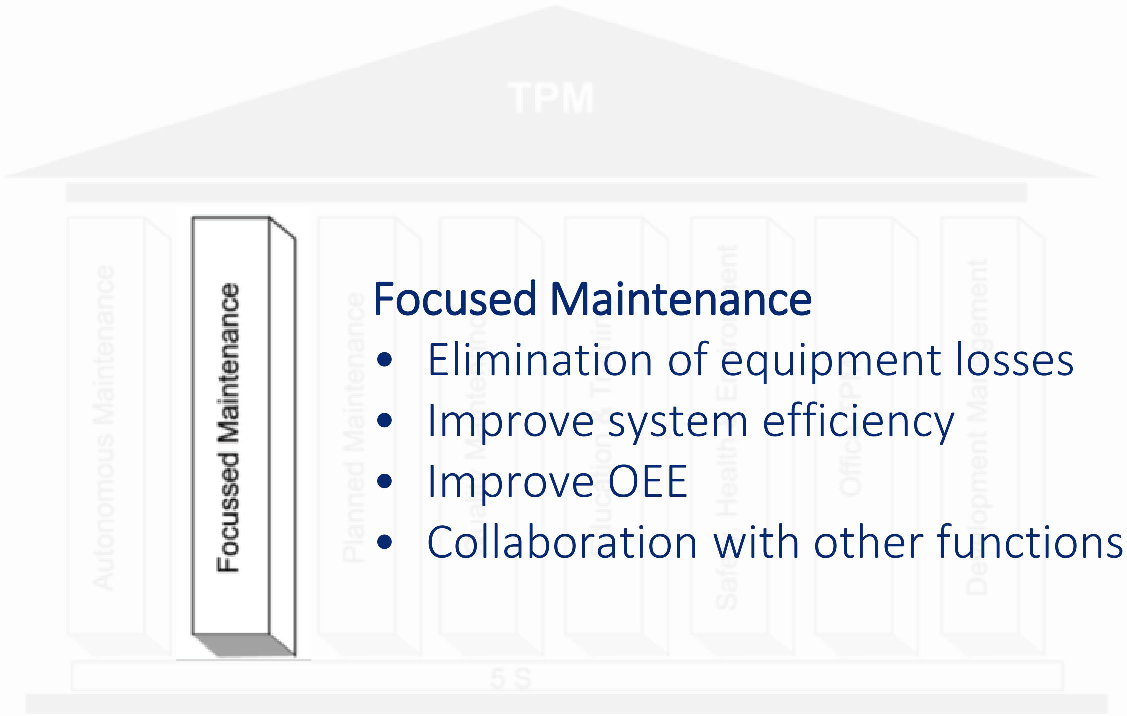


Total Productive Maintenance (TPM)

Autonomous Maintenance

- Operator maintenance
- Fostering operator ownership
- Cleaning, inspection and lubricating (CIL)

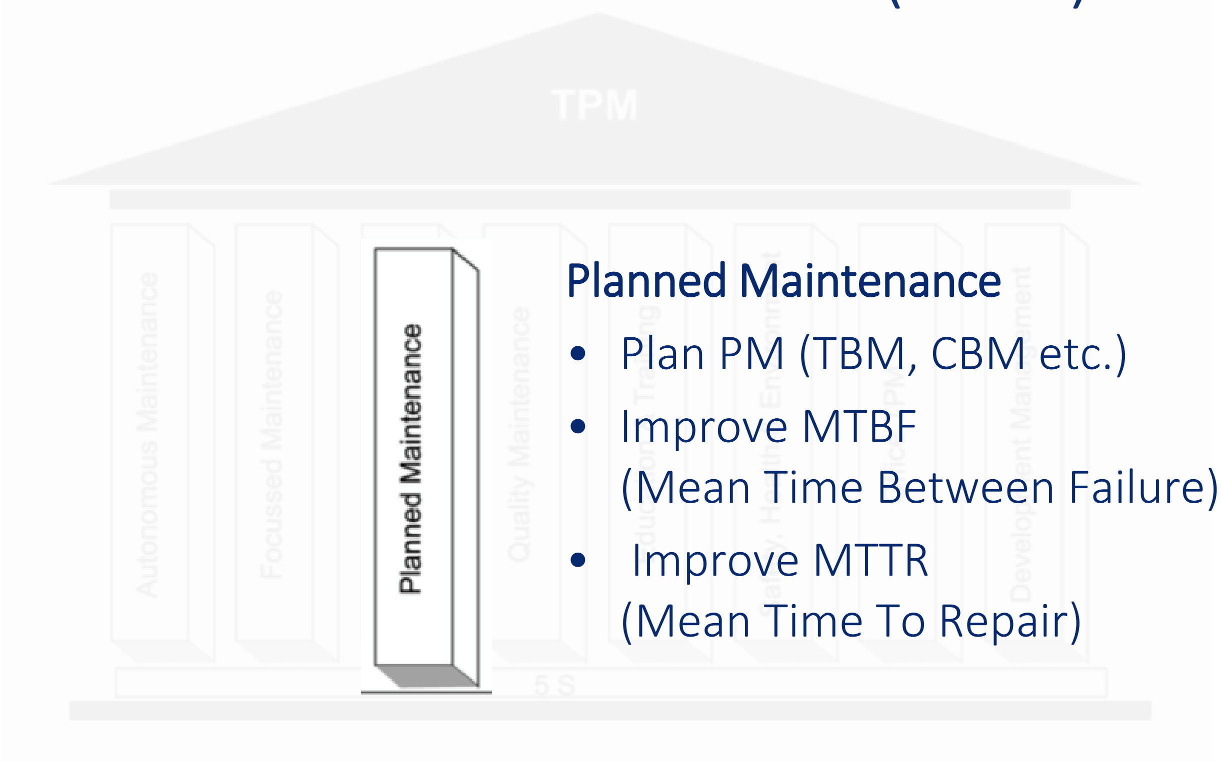
Total Productive Maintenance (TPM)



Focused Maintenance

- Elimination of equipment losses
- Improve system efficiency
- Improve OEE
- Collaboration with other functions

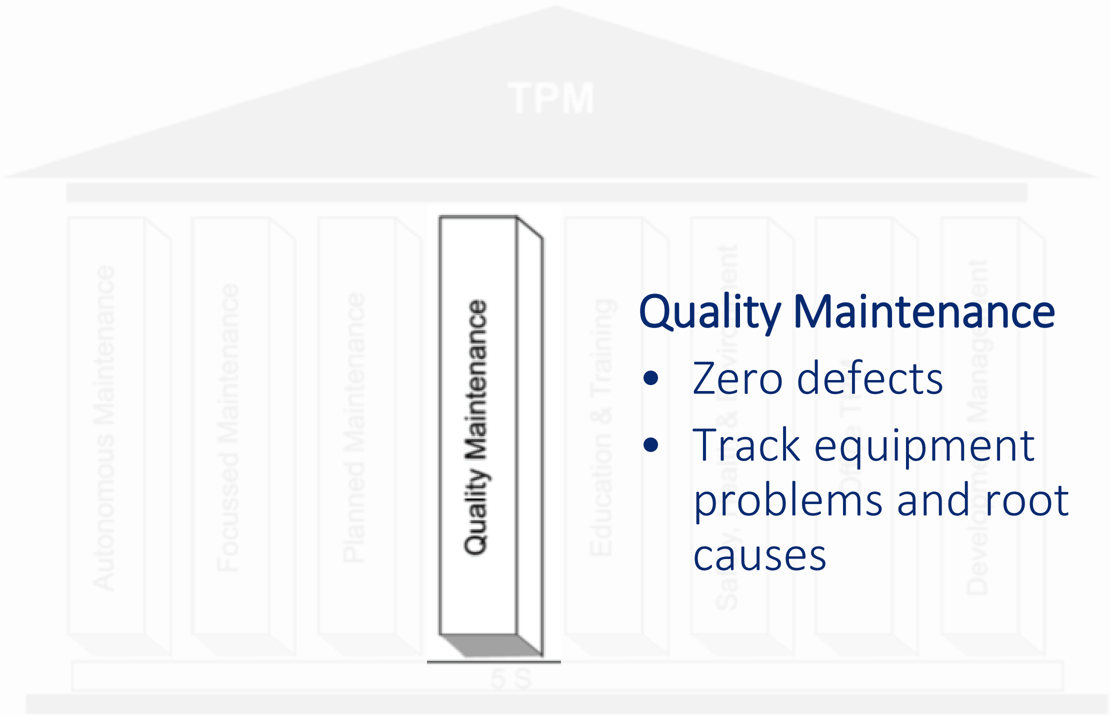
Total Productive Maintenance (TPM)



Planned Maintenance

- Plan PM (TBM, CBM etc.)
- Improve MTBF
  (Mean Time Between Failure)
- Improve MTTR
  (Mean Time To Repair)

Total Productive Maintenance (TPM)



Quality Maintenance

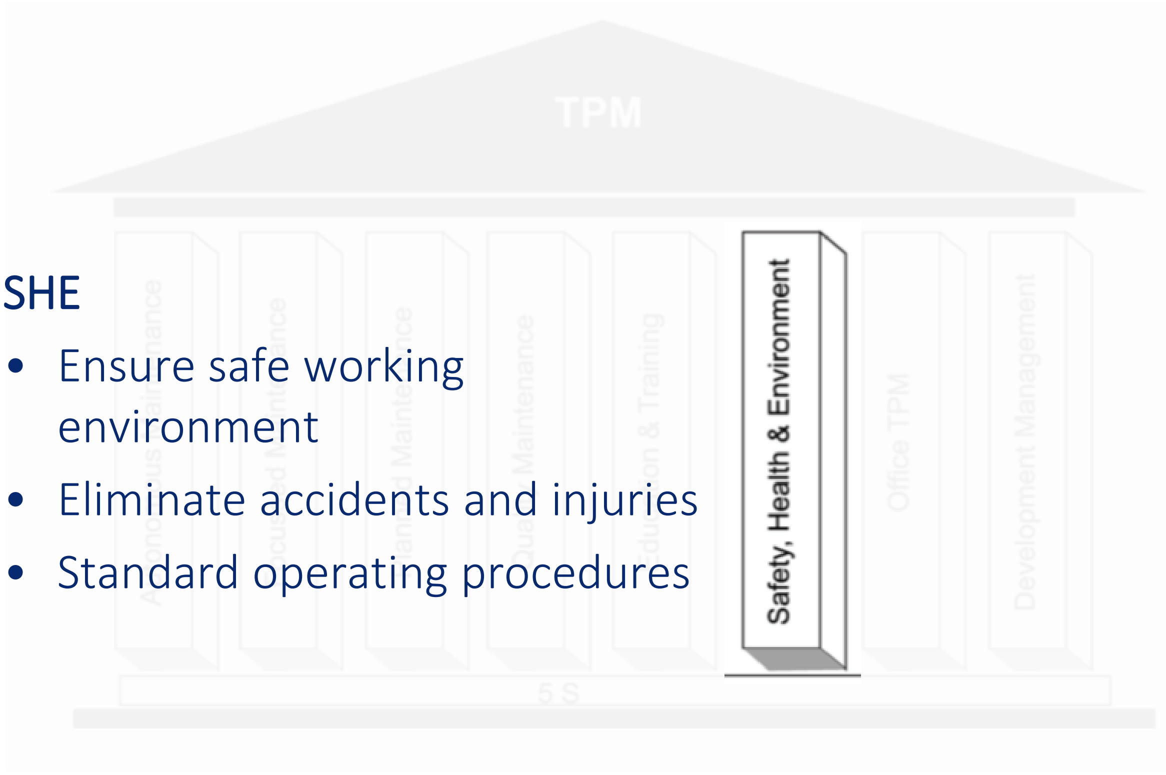
- Zero defects
- Track equipment problems and root causes

Total Productive Maintenance (TPM)

Education & Training

- Technical, quality, interpersonal skills
- Multi-skilled employees

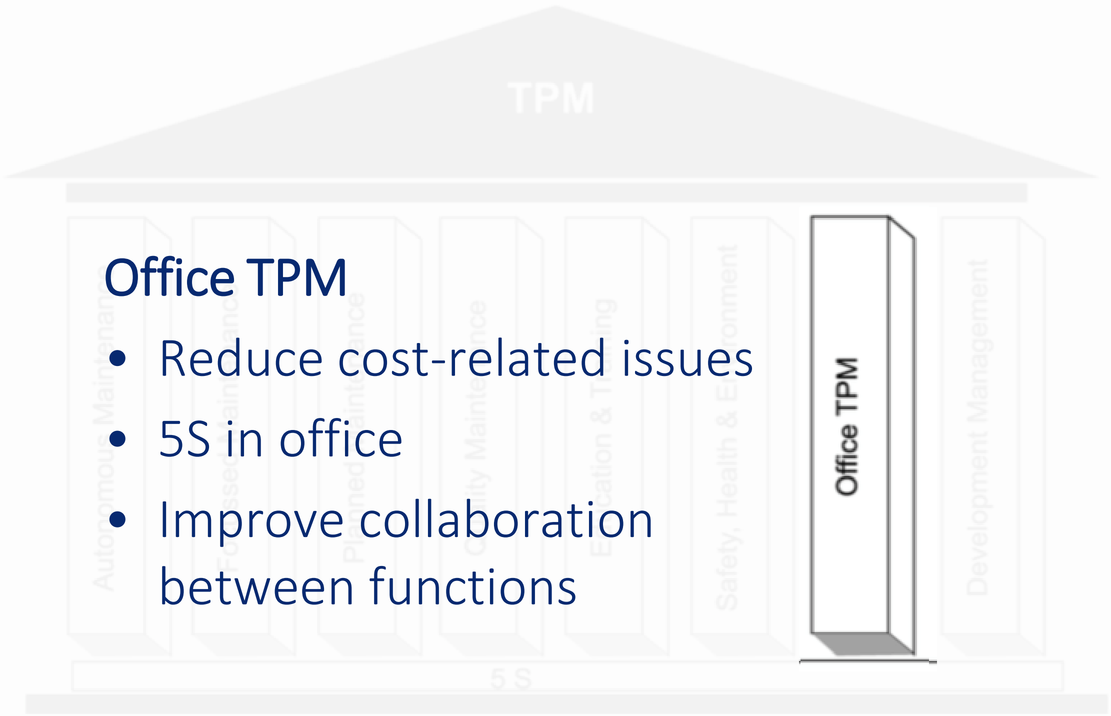
Total Productive Maintenance (TPM)



SHE

- Ensure safe working environment
- Eliminate accidents and injuries
- Standard operating procedures

Total Productive Maintenance (TPM)



Office TPM

- Reduce cost-related issues
- 5S in office
- Improve collaboration between functions

Total Productive Maintenance (TPM)

Development Management

- Maintenance Prevention
- Early Equipment Management
- Maintenance in design phase

Very important, often neglected!

3.1.8 Maintenance Engineering

If your plant does not have a Maintenance Engineering section, one should be established. The functions and responsibilities of new or existing maintenance engineering groups should be reviewed and revised to integrate and enhance the proactive maintenance organization. An alarming statistic indicates that up to 70% of equipment failures are self-induced. Finding the reasons for self-induced failures, and all failures, is a responsibility of maintenance engineering. Reliability engineering is the primary role of a maintenance-engineering group. Their responsibilities in this area should include:

- Evaluating Preventive Maintenance Action Effectiveness
- Developing Predictive Maintenance Techniques/Procedures
- Performing Condition Monitoring/Equipment Testing
- Analyzing PM/PdM/CM-CT Data for Optimizing Maintenance
- Employing Engineering Techniques to Extend Equipment Life, Including:
  - Specifications for new/rebuilt equipment
  - Precision rebuild and installation
  - Failed-part analysis
  - Root-cause failure analysis
  - Reliability engineering
  - Rebuild certification/verification
  - Age exploration
  - Recurrence control
- Performing Continuous Evaluation of Maintenance Skills Training Effectiveness
- Performing Selected Elements of Reliability Centered Maintenance (RCM)

Lean Maintenance

A volume in Life Cycle Engineering Series

Author(s):

Ricky Smith and Bruce Hawkins

ISBN: 978-0-7506-7779-0

Add to Favorites

Reliability-Centered Maintenance (RCM)

History:

- 1960; Aviation Industry
- Licencing of Boeing 747
- United Airlines (Nowland and Heap, 1968)
- Completely questioned *why* and *how* maintenance should be done

WEAR OUT CURVES

		UAL 1968		Broberg 1973	MSP 1982
	A	4%		3%	3%
	B	2%		1%	17%
	C	5%	4%	3%	
	D	7%	11%	6%	
	E	14%	15%	42%	
	F	68%	66%	29%	

Ranges from 8% to 23%

Ranges from 77% to 92%

WEAR OUT CURVES

A

Decision?

B

C

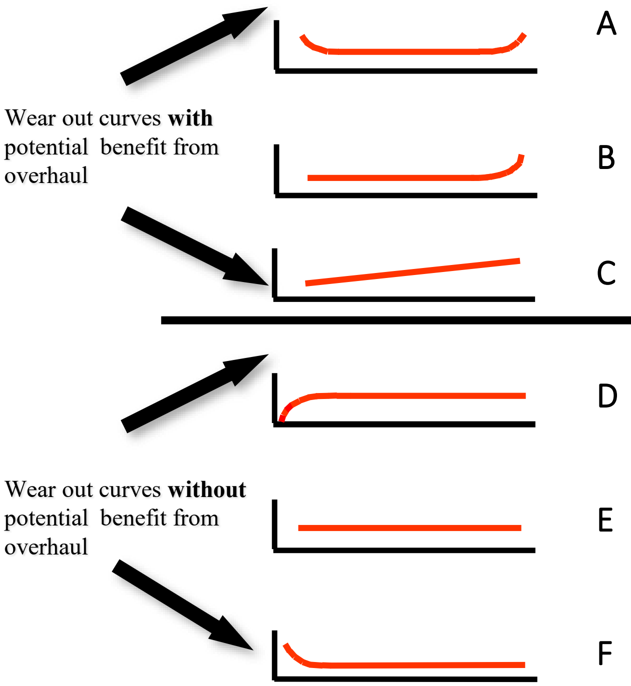
D

Decision?

E

F

WEAR OUT CURVES



<u>**Decision?**</u>

Perform scheduled maintenance

<u>**Decision?**</u>

Do not perform scheduled maintenance!

Reliability-Centered Maintenance (RCM)

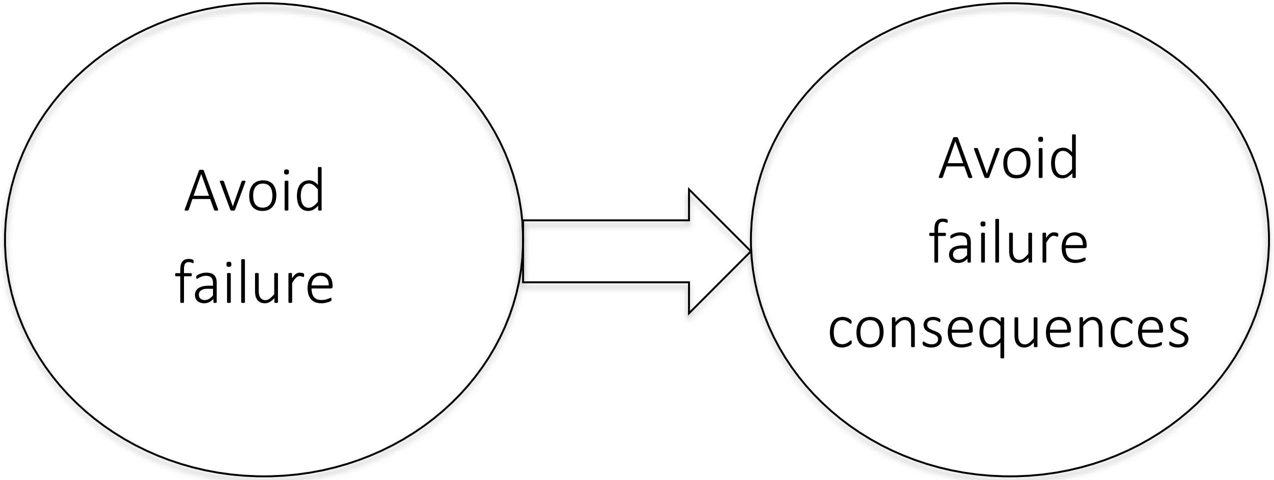
Versions of RCM:

- MSG-1 for Boeing 747
- MSG-2, MSG-3 etc. (Boeing 757, 767, 777)
- Equivalents for Concorde, Airbus etc.

MSG known as Reliability-Centered Maintenance (RCM)

RCM II = RCM outside aviation industry (e.g. manufacturing)
(popularized by John Moubray)

RCM proposed a shift in thinking:



Do only what ***must*** be done!

Reduce ***unnecessary*** maintenance!

Reliability-**Centered** Maintenance (RCM)

Reliability is put in the ***centre***!

Four basic features of RCM:

1. Preserve functions
2. Identify failure modes that can defeat the function
3. Prioritize function need
4. Select ***applicable*** and ***effective*** PM tasks for high priority failure modes

Applicable = if the task is performed, it will accomplish one of three reasons for preventive maintenance (*prevent or mitigate failure, detect onset of a failure, discover hidden failure*)
Effective = we are willing to spend the resources to do it

Condition-Based Maintenance (CBM)

History:

- Rio Grande Railway company (1940’s)
  - Monitoring engines to detect coolant, oil, and fuel leaks
- US Army
  - Monitoring military equipment

- 1950’s to 1970’s: Automotive, aerospace, military, manufacturing etc.
  - Can be used in any product than requires regular maintenance

Condition-Based Maintenance (CBM)

Monitor system performance, system health, root causes of failures, **forecasting** remaining useful life (RUL)

CBM utilizes Condition Monitoring, e.g. in production equipment:

- Vibration (any moving component)
- Thermography (temperature)
- Oil analysis (e.g. viscosity)
- Ultrasonic (high frequency sound)

- CBM is not only about sensors
  - Five senses is a very cheap version of CBM!

Table 3-4
PdM and Condition Monitoring

Predictive Technique	Application	Problem Detection
Vibration	Rotating machinery, e.g., pumps, turbines, compressors, internal combustion engines, gear boxes, etc.	Misalignment, imbalance, defective bearings, mechanical looseness, defective rotor blades, oil whirl, broken/worn gear teeth, etc.
Shock Pulse	Rotating machinery	Trends of bearing condition
Fluid Analysis (lubricants, coolants, feedwater, etc.)	Lubrication, cooling, hydraulic power, boiler and similar systems	Bearings & housings—wear particles, viscosity, contaminants, etc.
Infrared Thermographic Imaging	Electrical switchboards & distribution/control equipment, steam systems, bearing end caps, power electronics, anything generating heat	Loose electrical connections, worn contacts, faulty insulation, leaky steam traps, hot running bearings, overheating components
Ultrasonics	High pressure systems: hydraulics, steam, pneumatics, etc.	Leaks—through and by: valves, restrictors, fittings, etc.
Spectographic Analysis	Fluid and Gas Systems: liquid cooled circuit breakers, transformers, etc. Gas systems in firing/finishing operations or combustion sys., etc.	Contaminants, chemical constituents and proportion, hazards
Waveform/signature analysis (time and frequency domains)	Power Factor, power quality, Electronics: rectifiers, inverters, power supplies, regulators, etc).	System load characteristcs/Motor faults, degraded circuits, faulty solid state devices, etc.

Condition-Based Maintenance (CBM)

Monitor system performance, system health, root causes of failures, **forecasting** remaining useful life

1. **Diagnostics** = finding the fault after occurring, or in the process of the fault occurring (*fault not equal to failure*)

2. **Prognostics** = predicting future failures by analysing current and previous history

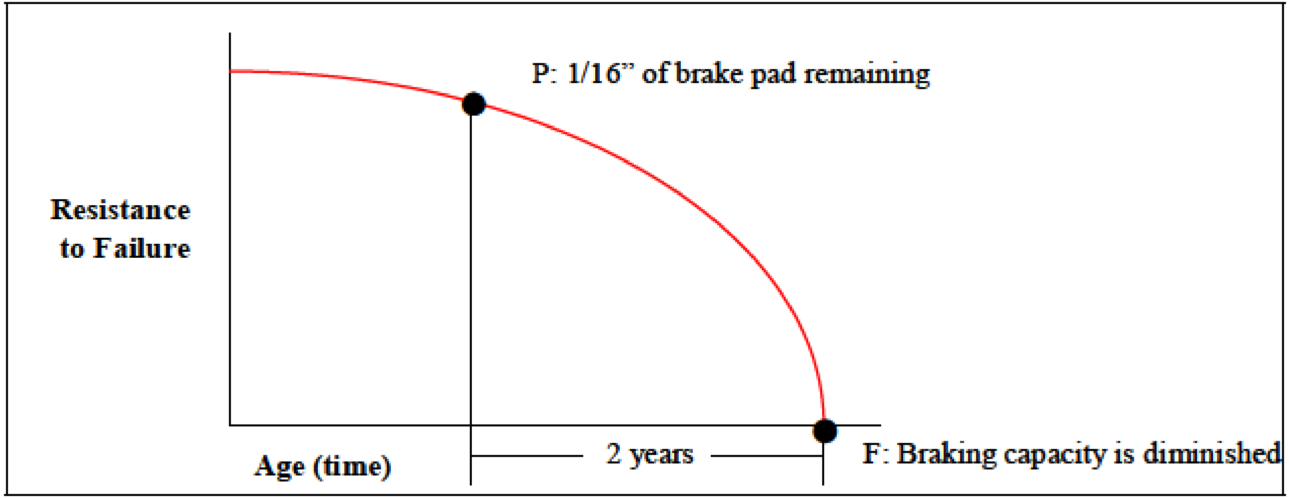
Condition-Based Maintenance (CBM)

CBM today:

- Advances in Information Technology
  - Collection and analysis of Big Data
  - Machine Learning (learning from data in contrast to formal hypotheses)
- Cheap sensors
- Data collection is not equal to data-driven decision making
  - Potential to collect huge amounts of data – information overload!
  - What parameters to monitor? What parameters are critical?
  - How to collect data?
  - What data to analyse?
  - How to manage levels? E.g. components, machines, systems
  - Which type of algorithm should be used?
  - How can we trust the data? (data quality)

Condition-Based Maintenance (CBM)

- PF curve – the heart of CBM
  - Describes equipment failure behaviour

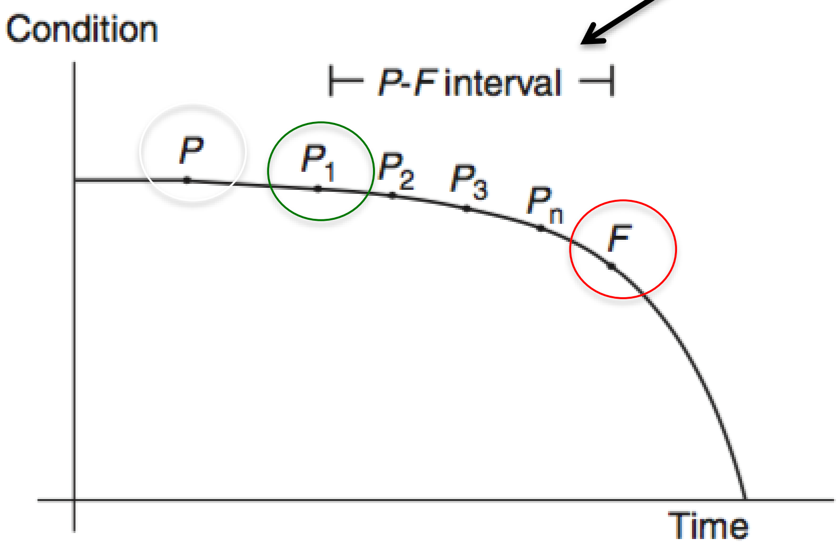


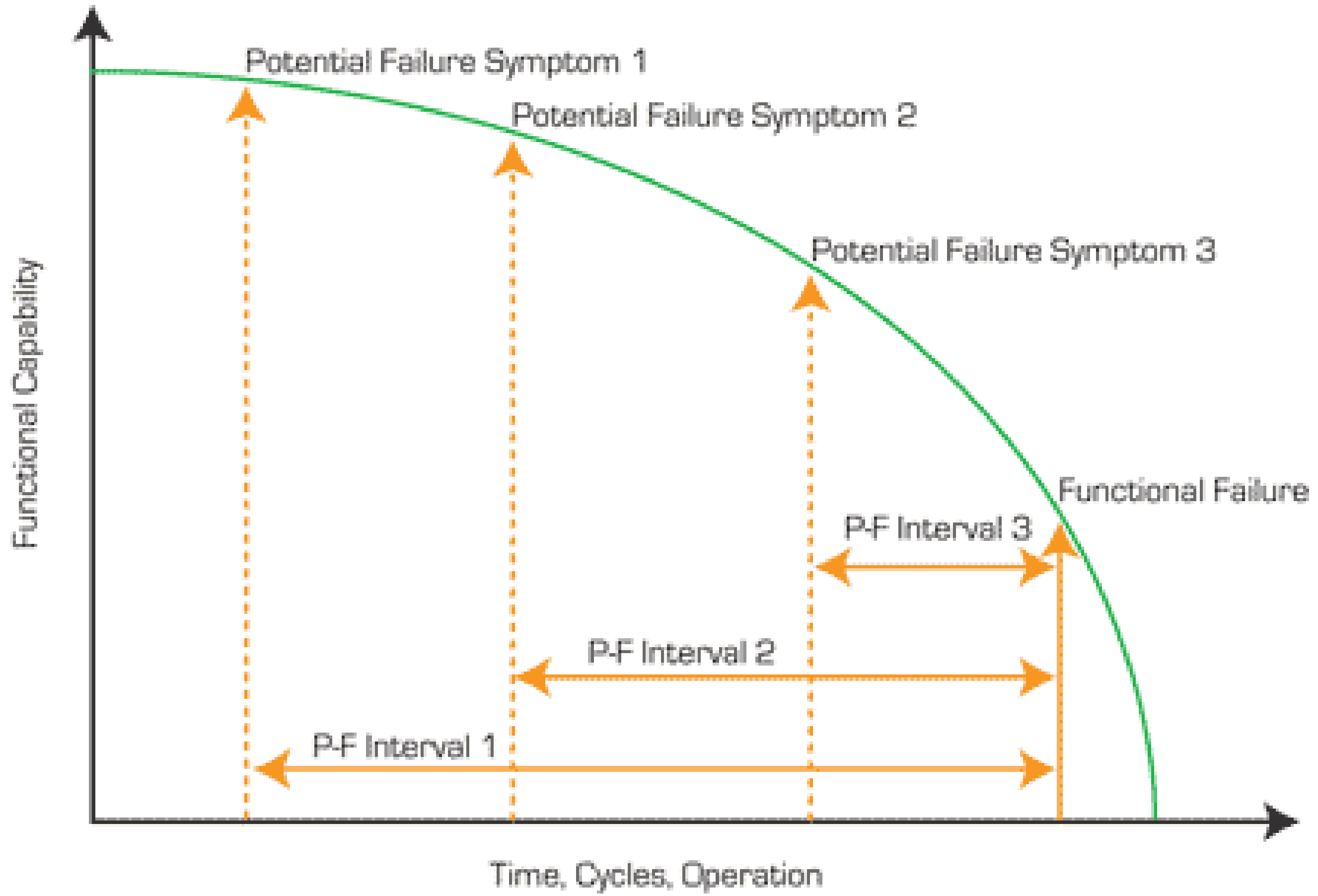
Condition-Based Maintenance (CBM)

P_1 = failure symptom is detectable

F = functional failure point (system fails)

Take action!




Potential Failure Symptom 1
Potential Failure Symptom 2
Potential Failure Symptom 3
Functional Failure
P-F Interval 3
P-F Interval 2
P-F Interval 1
Functional Capability
Time, Cycles, Operation

Summary

TPM, RCM, CBM are the three most common maintenance concepts, and widely used in industry

TPM, RCM, CBM are not competing, they are complementing each other:

TPM: holistic approach to equipment management

⇕

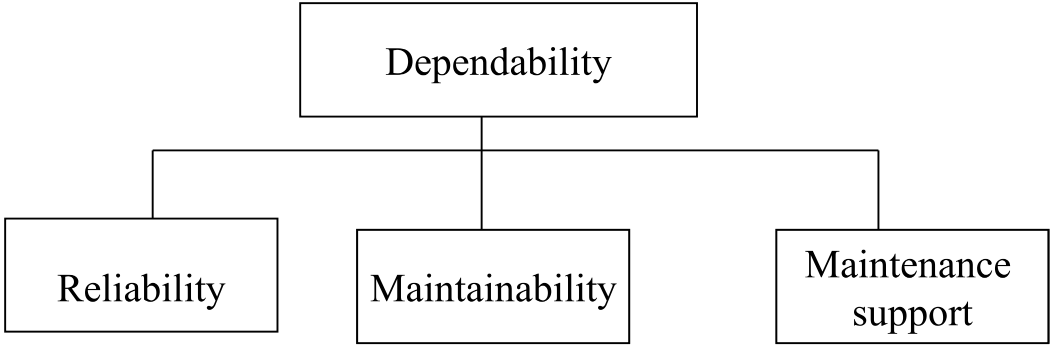
RCM: determine overall maintenance plan

⇕

CBM: monitor specific equipment

Maintenance fundamentals

The Concept of Dependability



Dependability

A collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance

Reliability

Reliability is the ability of an item to perform a required function under given conditions for a given time interval

Reliability may also be defined as a probability that an equipment will perform its intended function without failure for a specific time under defined conditions

Maintainability

Maintainability is the ability of an item under given conditions of use, to be retained in, or restored to, a State in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources

Note 1: The maintainability is also used as a measure of maintainability performance

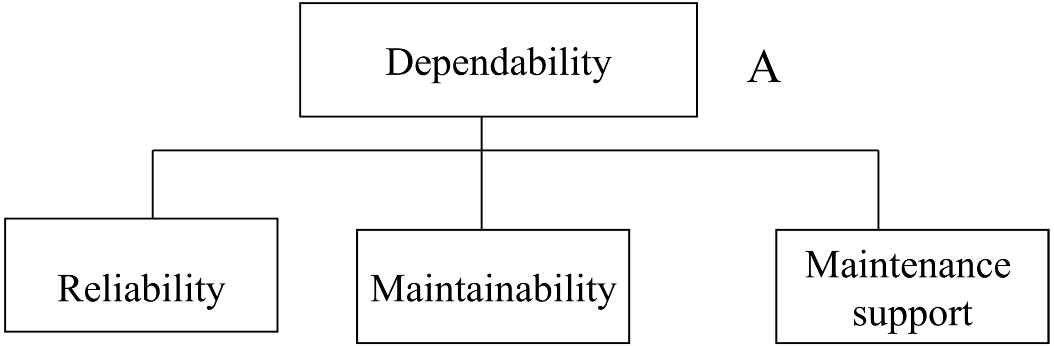
Note 2: The time characteristic of maintainability is the active maintenance time

Maintenance supportability

The ability of having the right maintenance support at the necessary place to perform the required, maintenance activity at a given instant of time or during a given time interval

Maintenance support is the resources, service and management to perform a maintenance action

The Concept of Dependability



MTTF/MTBF
R(t), F(t), f(t), λ(t)

MTTR

MTW

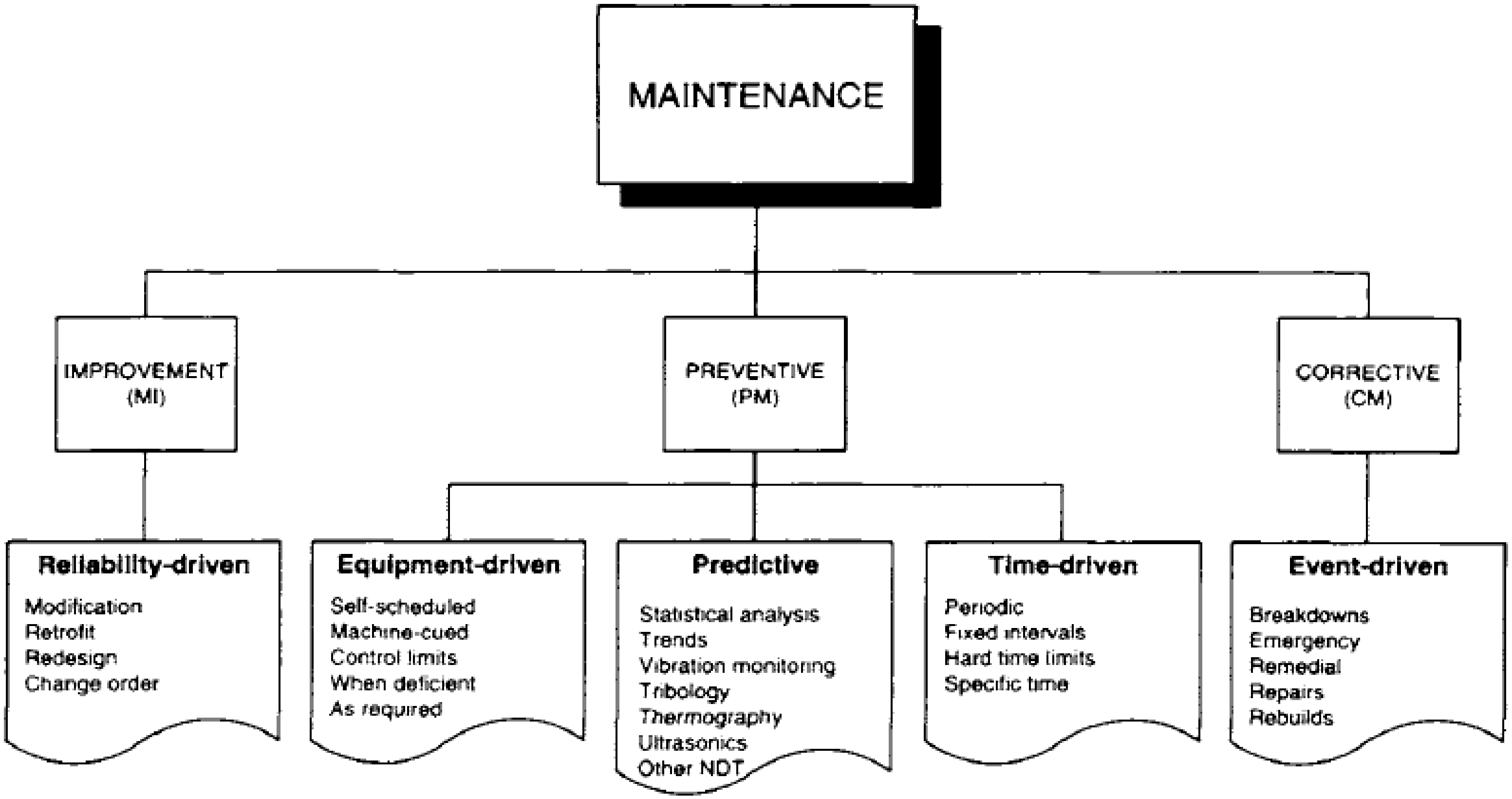


Figure 1.2 Structure of maintenance.

Inherent Reliability

The Little Black Book of Maintenance Excellence

The **inherent reliability** of a plant, system or device is the <u>maximum</u> achievable reliability based on configuration and component selection.

If operated correctly, maintained correctly and inspected on appropriate intervals, it will be possible to attain the full inherent reliability.

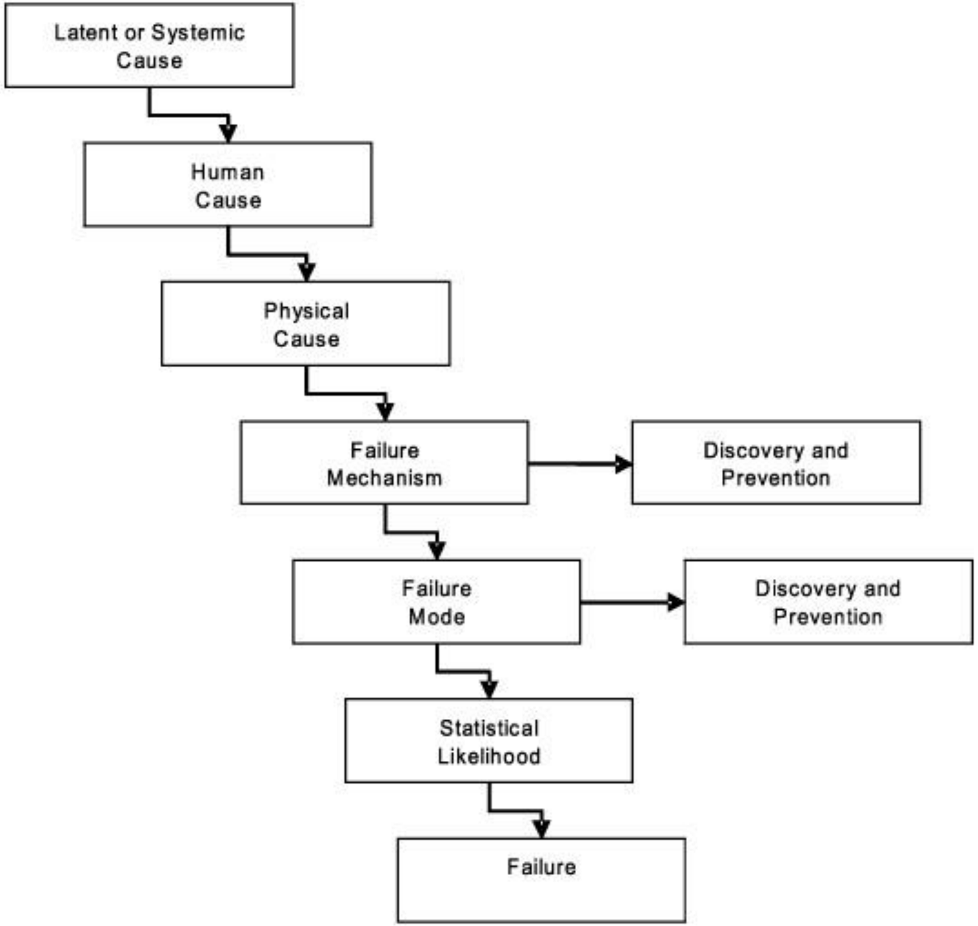
If poorly operated, poorly maintained or allowed to develop and retain defects, the reliability can be significantly less than the inherent reliability

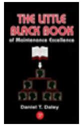
So the Reliability Management Process and the Maintenance Excellence Process go hand-in-hand.

If maintenance work management processes are not done in a manner that restores the inherent reliability, the reliability performance will continually degrade.

If the Reliability process is not working to provide an acceptable level of reliability, the maintenance processes will end up "chasing-their-tail", dealing with too-frequent and unexpected breakdowns.

The Path of Failure





The value of understanding the Path to Failure is knowing that both the failure mechanism and the defect can be discovered before failure, and that the failure can be prevented. **Wise people also learn from failures, and they identify the three levels of cause in time to take corrective action.**

In order to create Predictive Maintenance tasks, you need to understand the failure mechanisms that "are" at work and those that "can be" at work. That is an important point to emphasize. Many people simply copy the PM tasks recommended by the manufacturer, and then perform them by rote without really understanding why they are doing them.

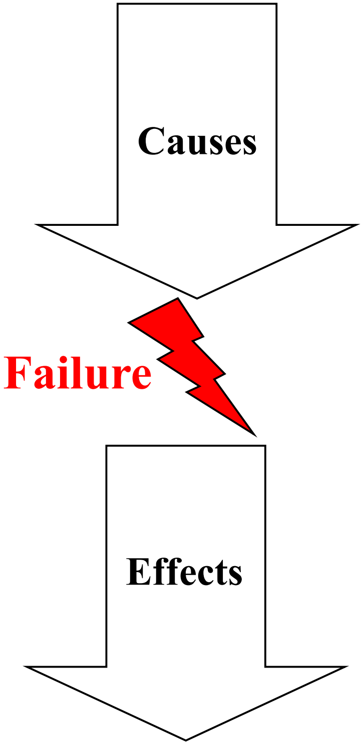
Predictive Maintenance tasks are intended to:

1. Evaluate failure mechanisms that are known to be at work.
2. Identify failure mechanisms that can be at work.

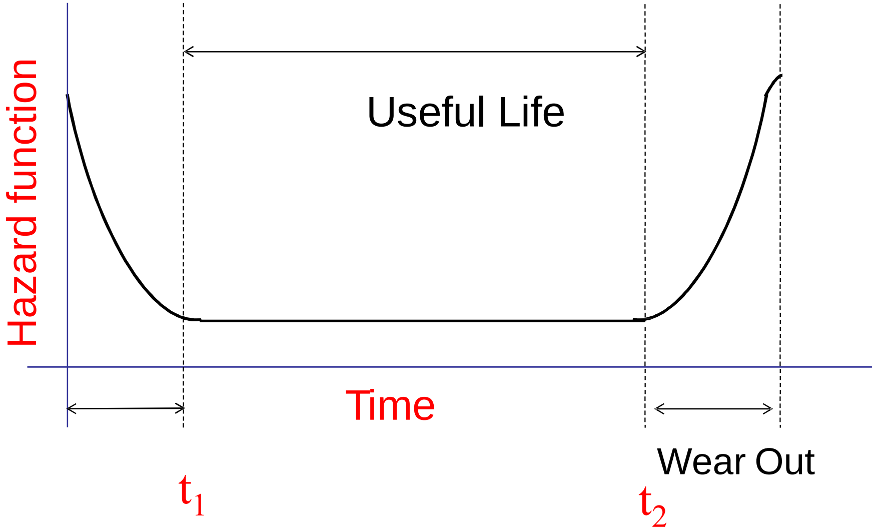
Aim of Failure analysis

- Find
- Assess
- Reduce
- Eliminate

- Find
- Assess
- Reduce
- Eliminate



Bath-tub curve



Infant Mortality Failure Period

In its early life, an item population exhibits a high failure rate, due mainly to manufacturing weaknesses, including:

- Poor joints and connections.
- Damaged components.
- Chemical impurities.
- Dirt and contamination.
- Assembly errors.

Useful Life Failure Period

During the useful life failure period, t_1 to t_2, the failure rate remains substantially constant, and, although some failures may still arise from manufacturing weaknesses or wear-out, the majority of failures are caused by the operating stresses to which the item is subject in its particular application (e.g., temperature, electrical and environmental stresses) and occur randomly (without any time-dependent pattern). During this period, when the failure rate is considered to be constant, the negative exponential distribution describes the times to failure.

The useful life failure period is the interval of most interest from a reliability prediction standpoint because, if a rigorous reliability programme is applied throughout a project lifetime, it is assumed that:

- The majority of early life failures will normally be eliminated before an item enters service.
- An in-service maintenance policy will ensure that items are replaced **before** wear-out becomes a significant problem.

Wear-Out Failure Period

During the wear-out failure period, the failure rate increases due mainly to deterioration of the item through prolonged exposure to operating and environmental stresses, which may include:

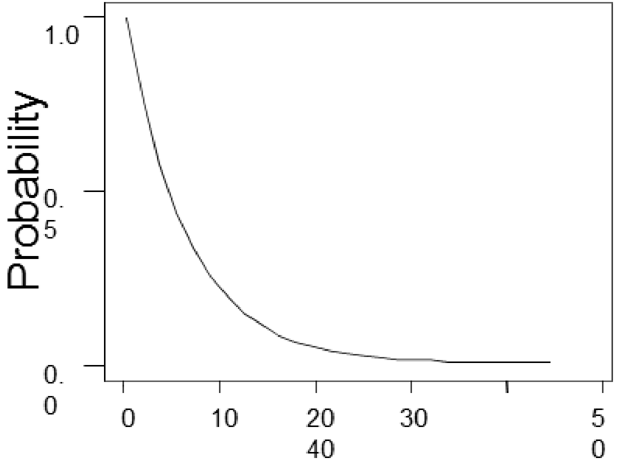
- Insulation breakdown.
- Wear or fatigue.
- Corrosion.
- Oxidation.

Normally, wear-out failures are avoided by replacing an item, either on the basis of fixed life replacement or **on-condition** monitoring. Even so, eventually the system becomes troublesome in use and is probably best replaced.

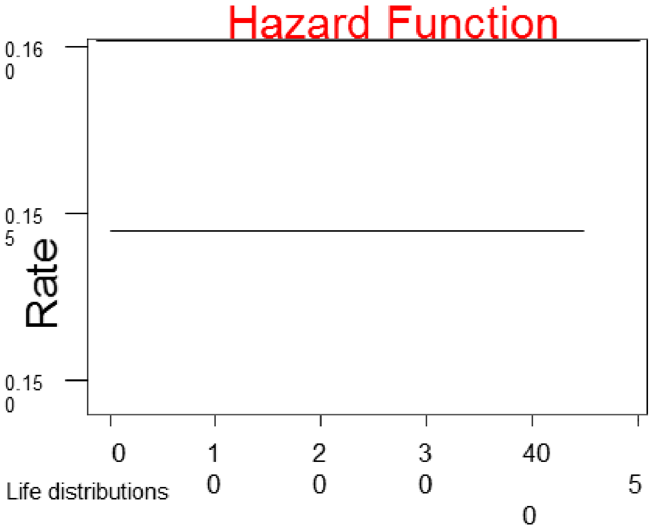
Exponential distribution

- Simplest of all life models
- One parameter, λ
- PDF, $f(t) = \lambda e^{-\lambda t}$
- CDF, $F(t) = 1 - e^{-\lambda t}$ and $R(t) = e^{-\lambda t}$
- Hazard function, $h(t) = \lambda$ i.e. constant
- MTBF = $1/\lambda$ and failure rate = λ
- $1/\lambda$ is the 63rd percentile i.e. time at which 63% of population will have failed

Exponential distribution



Survival Function



Weibull distribution

- Most useful lifetime in reliability analysis
- 2 parameter Weibull
  - Shape parameter - β
  - Scale parameter - η
- When $\beta < 1$ decreasing hazard function
- When $\beta > 1$ increasing hazard function
- When $\beta = 1$ constant hazard function
- η is the characteristic life, 63rd percentile

Probability plotting

- Graphical estimation method
- Based on cumulative distribution function CDF - F(t)
- Probability papers for parametric distributions, e.g. Weibull
- Axis is transformed so that the true CDF plots as a straight line
- If plotted data fits a straight line then the data fits the appropriate distribution
- Parameter estimation

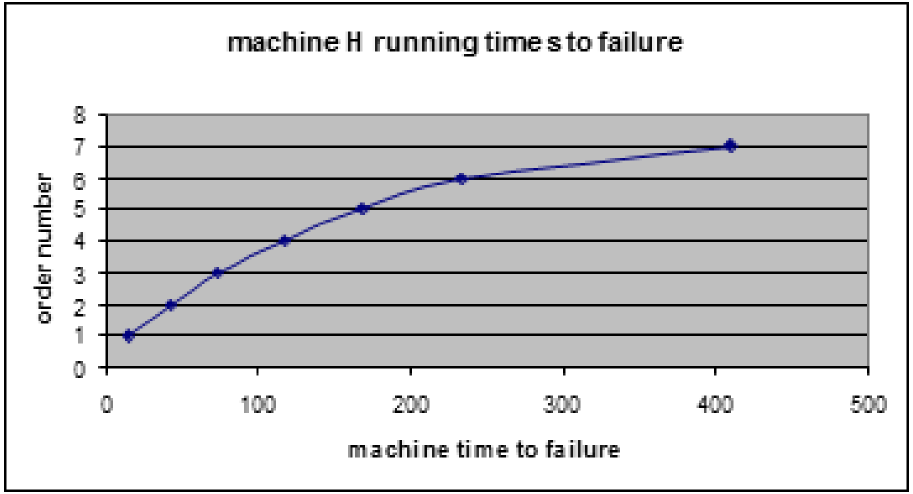
Assumptions

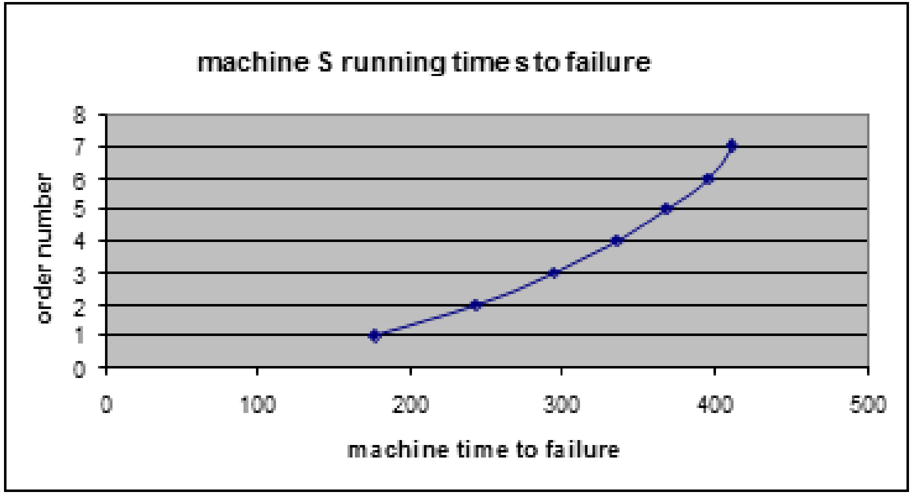
- Data must be Independently Identically Distributed (IID)
  - No causal relationship between data items
  - No trend in the time between failures
  - All having the same distribution
- Non-repaired items
- Repaired items with no trend in the time between failures

Example of test for trend

- Machine H fails at the following running times (hours):
  - 15, 42, 74, 117, 168, 233, and 410
- Machine S fails at the following running times (hours):
  - 177, 242, 293, 336, 368, 395, and 410

Trend Analysis





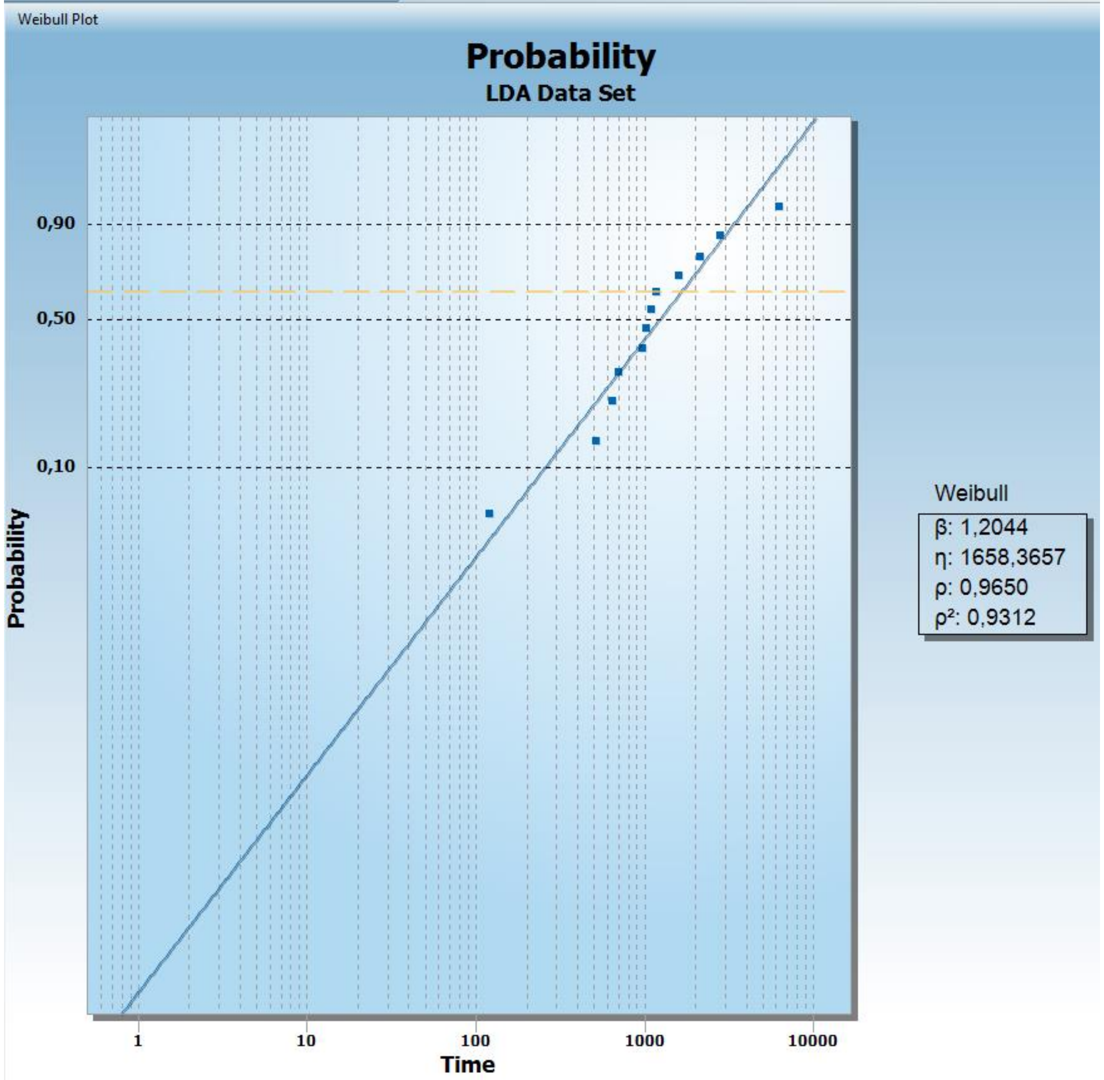
This system is getting better with time, the failure times are getting further and further apart

This system is getting worse with time, the failure times are getting closer and closer together

In neither case can Weibull analysis be used as there is trend in the data

Example: Pumps

pump no	age at failure
1	1180
2	6320
3	1030
4	120
5	2800
6	970
7	2150
8	700
9	640
10	1600
11	520
12	1090



Weibull Plot
Probability
LDA Data Set
0,90
0,50
0,10
Probability
1
10
100
1000
10000
Time
Weibull
β: 1,2044
η: 1658,3657
ρ: 0,9650
ρ²: 0,9312

Example: Pumps

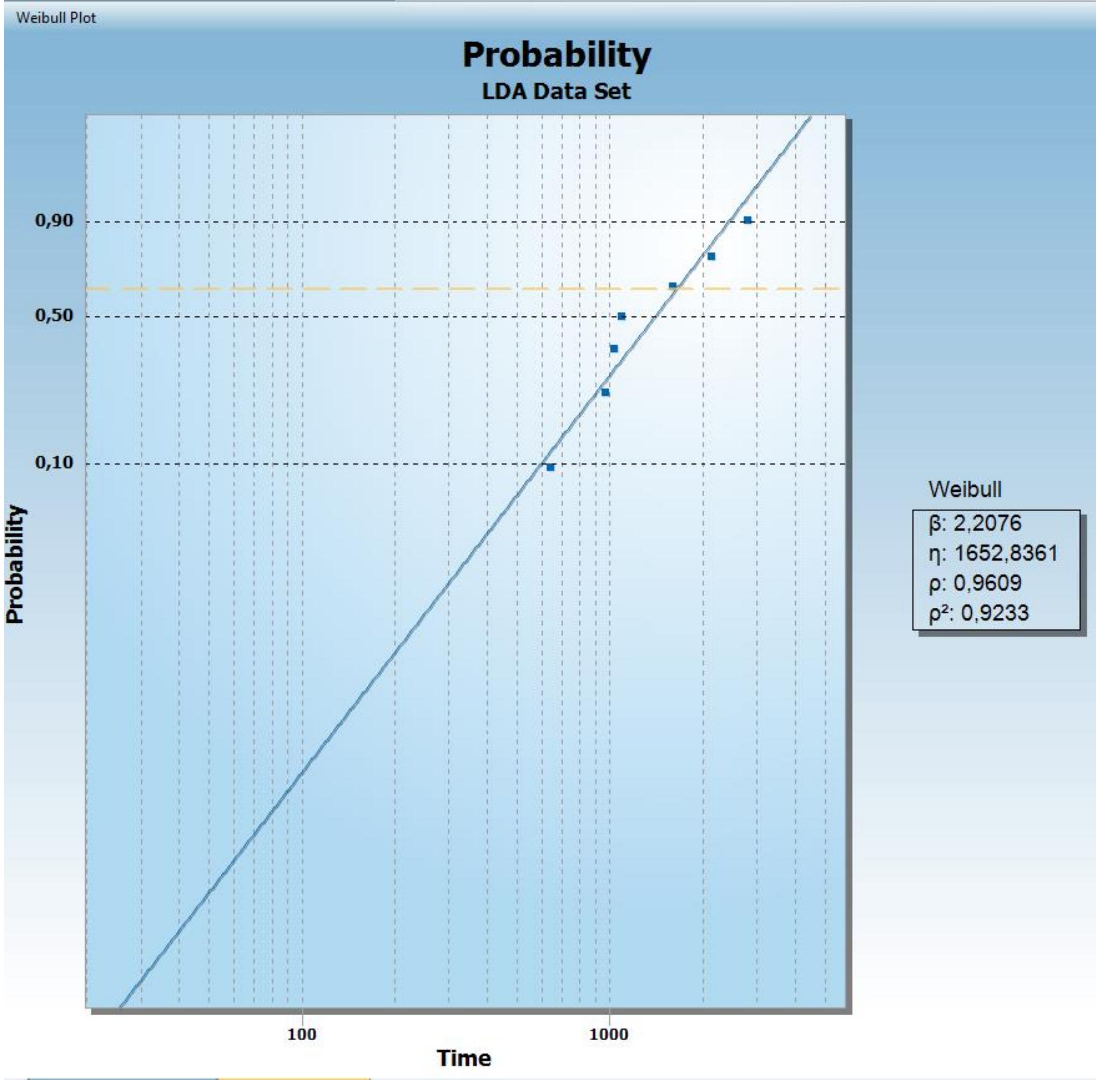
- Two dominant failure modes
  - –Impeller failure (i)
  - –Motor failure (m)

pump no	age at failure	failure mode
1	1180	m
2	6320	m
3	1030	i
4	120	m
5	2800	i
6	970	i
7	2150	i
8	700	m
9	640	i
10	1600	i
11	520	m
12	1090	i

Example: Pumps

- Two dominant failure modes
  - –Impeller failure (i)
  - –Motor failure (m)

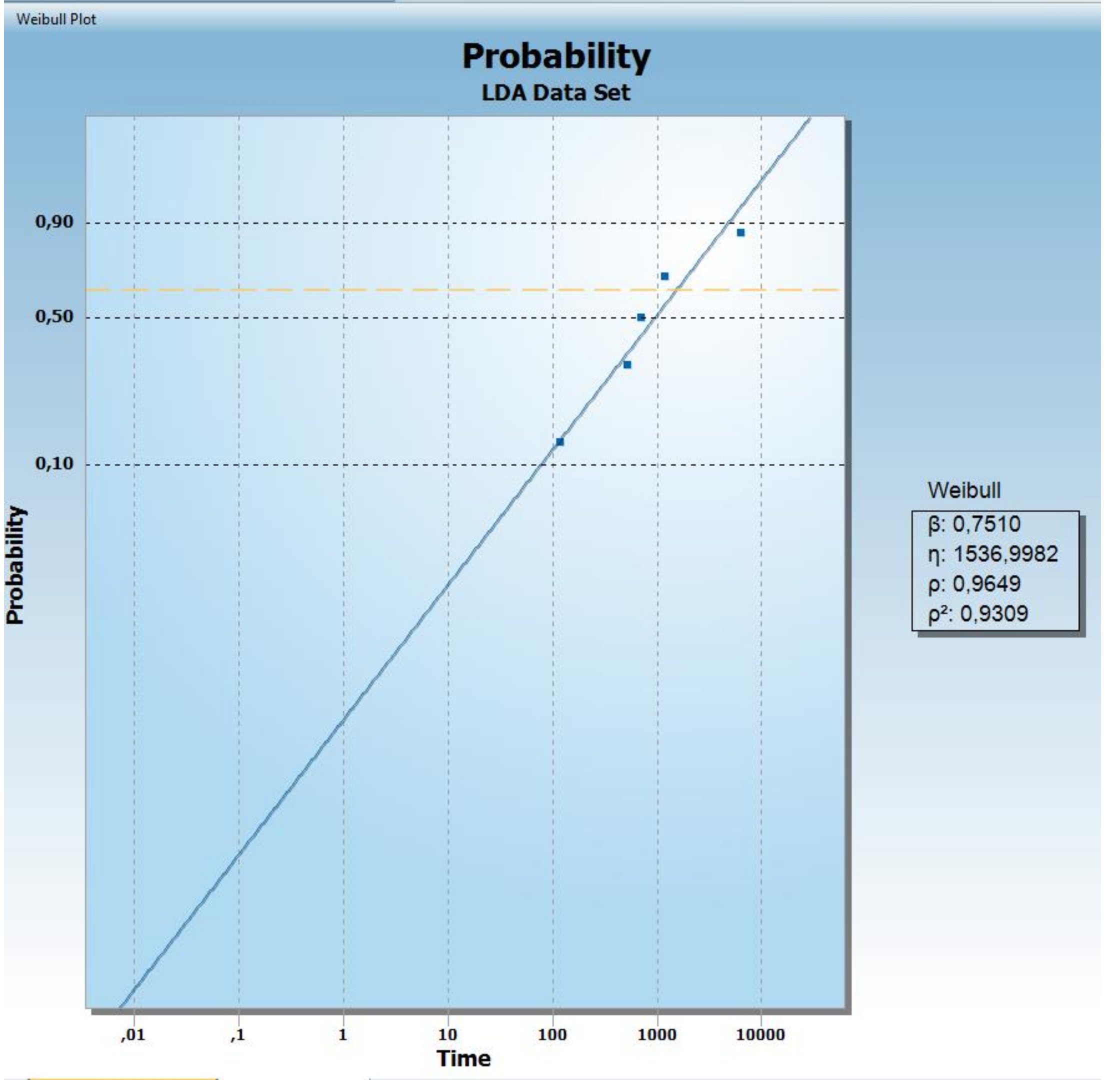
pump no	age at failure	failure mode
3	1030	i
5	2800	i
6	970	i
7	2150	i
9	640	i
10	1600	i
12	1090	i


Weibull Plot
Probability
LDA Data Set
0,90
0,50
0,10
Probability
100
1000
Time
Weibull
β: 2,2076
η: 1652,8361
ρ: 0,9609
ρ²: 0,9233

Example: Pumps

- Two dominant failure modes
  - –Impeller failure (i)
  - –Motor failure (m)

pump no	age at failure	failure mode
1	1180	m
2	6320	m
4	120	m
8	700	m
11	520	m


Weibull Plot
Probability
LDA Data Set
0,90
0,50
0,10
Probability
,01
,1
1
10
100
1000
10000
Time
Weibull
β: 0,7510
η: 1536,9982
ρ: 0,9649
ρ²: 0,9309

AVANCEZ
1829
CHALMERS

CHALMERS