Certified Maintenance & Reliability Professional (CMRP) BOK Guidance Course Pillar 3

Presented by

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Pillar 3 – Equipment Reliability

Concept & strategy

This subject area describes two kinds of activities that apply to the equipment and processes for which the maintenance and reliability professional is accountable.

First are those activities used to assess the current capabilities of the equipment and processes in terms of their reliability, availability, maintainability, and criticality.

Second are the activities used to select and apply the most appropriate maintenance practices, so that the equipment and processes continue to deliver their intended capabilities in the safest and most cost-effective manner.

Pillar 3 – Equipment Reliability

Concept & strategy

What is Reliability?

"The probability that an item will perform a required function without failure under stated conditions for a stated period of time."

“The probability of failure-free performance over an item's useful life, or a specified timeframe, under specified environmental and duty-cycle conditions”

“Consistency and validity of test results determined through statistical methods after repeated trials.”

Often expressed as per mean time between failures (MTBF) or reliability coefficient. Also called quality over time.

Pillar 3 – Equipment Reliability

Concept & strategy

What is Reliability?

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Example from Ancient Egypt

"As concerns the gold ring set with an Emerald, we guarantee that for 20 years the emerald will not fall out of the gold ring. If the emerald should fall out of the gold ring before the end of 20 years, we shall pay unto Bel-Nadin-Shumu and indemnity of 10 mana of silver."

Record found on a clay tablet in Egypt - 429. BC

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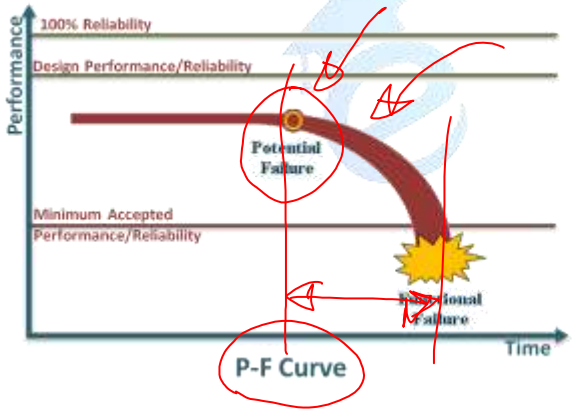
Concept & strategy

Failures and Performance Relation:

Failures cause significant performance and reliability decrease.



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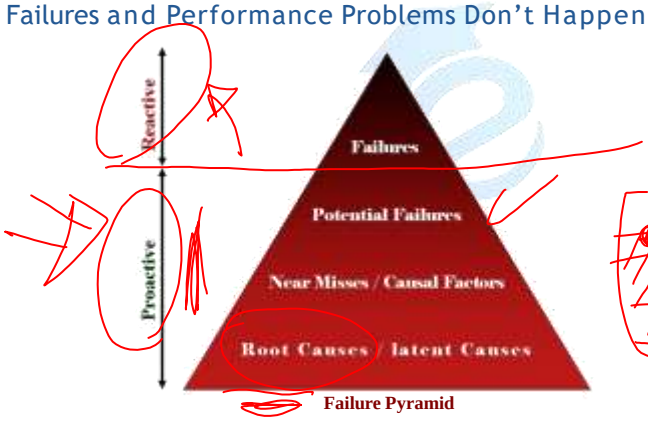
Concept & strategy

What is Reactive and What is Proactive

- Treating Functional Failures is Reactive
- Failures and Performance Problems Don't Happen All of a Sudden.



Failure Pyramid

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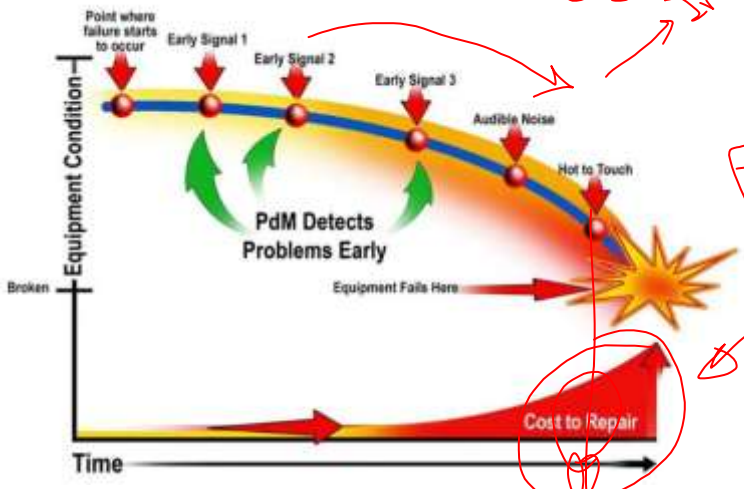
Concept & strategy

- P-F Curve – A Base for Maintenance Management



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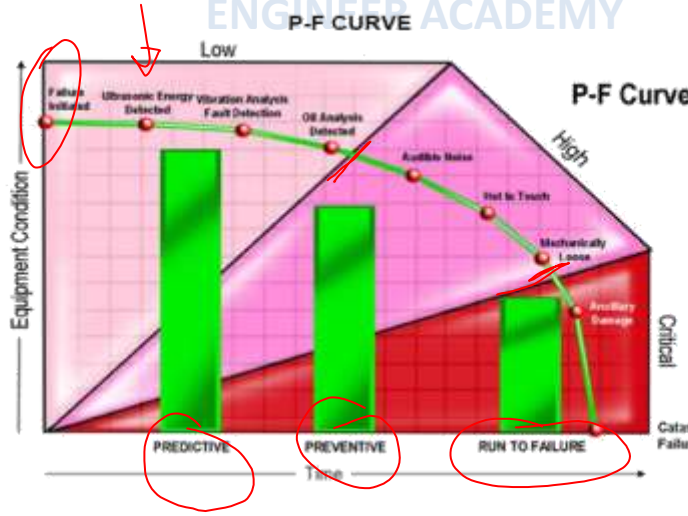
Concept & strategy

- P-F Curve – A Base for Maintenance Management



Pillar 3 – Equipment Reliability

3.1 Determine equipment reliability expectations

- Identify reliability goals
- Identify process expectations

Pillar 3 – Equipment Reliability

3.1 Determine equipment reliability expectations

What is Reliability?

Reliability 'by the book'=$R_{(t)} = e^{-\lambda t}$

Reliability 'by the book'=$R(t) = \frac{1}{e^{\frac{t}{MTBF}}}$

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3.1 Determine equipment reliability expectations

What is Reliability?

Example 1

A hydraulic system, which supports a machining center, has operated 3600 hours in the last two years. The plant's CMMS system indicated that there were 12 failures during this period. What is the reliability of this hydraulic system if it is required to operate for 20 hours or for 100 hours?

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3.1 Determine equipment reliability expectations

What is Reliability?

MTBF = operating time / # of failures = 3600 / 12 = 300 hours

Failure rate = 1 / MTBF = 1/ 300 = 0.003334 failures / hour

Reliability for 20 hours of operations,

$$R_{(t)} = e^{(-\lambda t)}$$

$$R_{(20)} = e^{-(0.003334)(20)} = 93.55\%$$

Reliability for 100 hours of operations,

$$R_{(100)} = e^{-(0.003334)(100)} = 71.65\%$$

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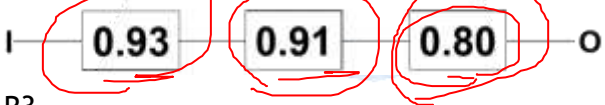
1. Determine equipment reliability expectations

What is Reliability?

Series Systems -Reliability

- A system whereby the failure of a single machine shuts down the entire system is said to be a "series designed system"



Rs = R1 x R2 x R3

Rs = 0.93 x 0.91 x 0.80 = 0.677 or 67.7%

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1. Determine equipment reliability expectations

What is Reliability?

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Series Systems -Reliability

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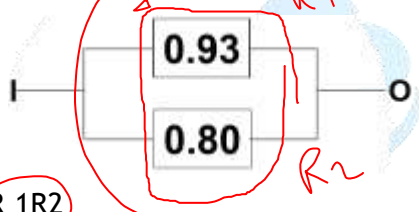
Pillar 3 – Equipment Reliability

3.1 Determine equipment reliability expectations

What is Reliability?

Active Parallel Systems -Reliability



Rs = R1 + R2 - R 1R2

Rs = 0.93 + 0.80 -0.93 x 0.80 = 0.986 or 98.6%

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3.1 Determine equipment reliability expectations

What is Reliability?

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What is the expectations for required reliability for airplanes?

How many flights per day?

102,465 flights per day

		Reliability Estimates					
		99%	99.90%	99.99%	99.999%	99.9999%	99.99999%
Daily Flights	102,465	1,025	102	10	1	0	0
Monthly Flights	3,073,950	30,740	3,074	307	31	3	0
Yearly Flights	37,399,725	373,997	37,400	3,740	374	37	4

Pillar 3 – Equipment Reliability

3.1 Determine equipment reliability expectations

The foundations on which equipment reliability and availability requirements are formed are:

- Business plan goals
- Stakeholder expectations

Pillar 3 – Equipment Reliability

3.1 Determine equipment reliability expectations

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To enable the development of meaningful and measurable equipment reliability and availability expectations the following is required:

- Knowledge of the plant processes and business objectives.
- An understanding of regulatory and code requirements
- Inherent design capabilities.

Pillar 3 – Equipment Reliability

3.2 Evaluate equipment reliability and identify improvement opportunities

- Measure and track performance
- Determine best demonstrated performance
- Analyze gaps

Pillar 3 – Equipment Reliability

3.2 Evaluate equipment reliability and identify improvement opportunities

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Evaluating equipment reliability begins with selecting:

- Where to measure
- How to measure
- When to measure

Consistent and accurate data collection methods are essential

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3.2 Evaluate equipment reliability and identify improvement opportunities

Major factors in establishing a performance measurement system are:

- Cost of data collection
- Data quality
- Data completeness
- Extrapolation from partial coverage
- Matching performance measures to their purpose
- Understanding unnecessary influences in the data
- Timeliness of data for measures
- Use of measures in allocation of funding
- Responsibility for measures, and limited control over the process

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3.2 Evaluate equipment reliability and identify improvement opportunities

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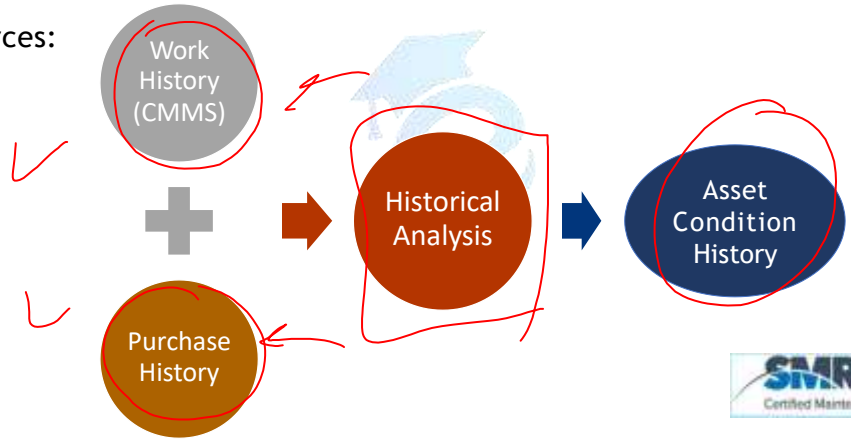
Some considerations when measuring asset condition & reliability:

Data Sources:



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3.2 Evaluate equipment reliability and identify improvement opportunities

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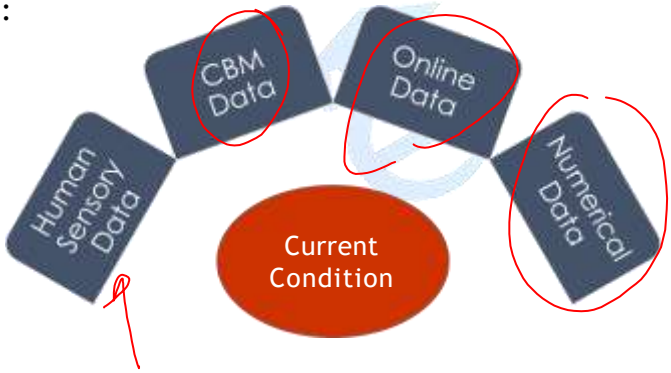

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3.2 Evaluate equipment reliability and identify improvement opportunities

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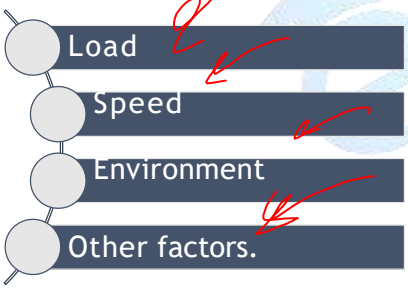
Analysis of performance data must also take into account some factors that may influence performance like:



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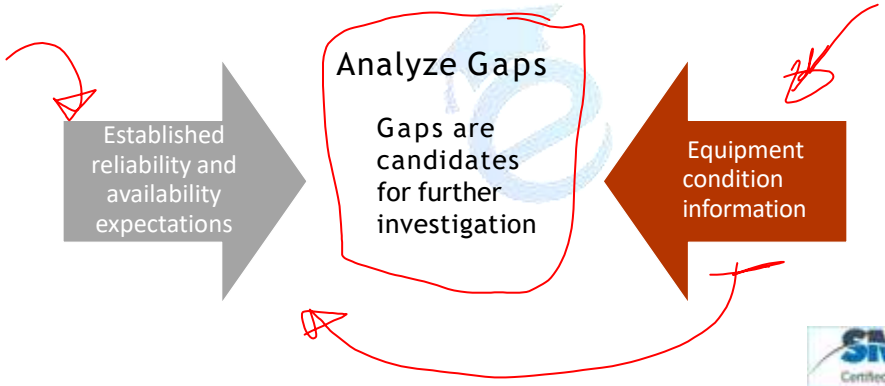
3.2 Evaluate equipment reliability and identify improvement opportunities

Equipment condition investigation



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3.2 Evaluate equipment reliability and identify improvement opportunities

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Equipment not meeting performance expectations may be analyzed using a variety of methods:

- Root cause analysis
- Weibull analysis.
- … etc

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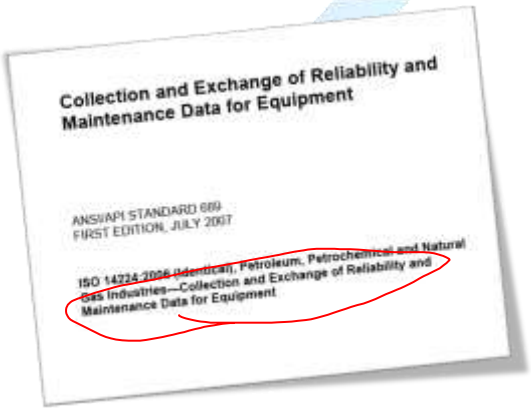
3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

Failure definitions and nomenclature (According to ISO 14224)



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3.2 Evaluate equipment reliability and identify improvement opportunities

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Root Cause Failure Analysis

Failure definitions and nomenclature (According to ISO 14224)

failure
termination of the ability of an item to perform a required function

NOTE 1 After the failure, the item has a fault.

NOTE 2 "Failure" is an event, as distinguished from a "fault," which is a state.

failure cause
root cause
circumstances associated with design, manufacture, installation, use and maintenance that have led to a failure

fault
state of an item characterized by inability to perform a required function, excluding such inability during preventive maintenance or other planned actions, or due to lack of external resources

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3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

Failure definitions and nomenclature (According to ISO 14224)

common-cause failure
failures of different items resulting from the same direct cause, occurring within a relatively short time, where these failures are not consequences of another

NOTE Components that fail due to a shared cause normally fail in the same functional mode. The term common mode is, therefore, sometimes used. It is, however, not considered to be a precise term for communicating the characteristics that describe a common-cause failure.

hidden failure
failure that is not immediately evident to operations and maintenance personnel

NOTE Equipment that fails to perform an "on demand" function falls into this category. It is necessary that such failures be detected to be revealed.

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3.2 Evaluate equipment reliability and identify improvement opportunities

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Root Cause Failure Analysis

Failure definitions and nomenclature (According to ISO 14224)

critical failure
failure of an equipment unit that causes an immediate cessation of the ability to perform a required function

NOTE 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.

non-critical failure
failure of an equipment unit that does not cause an immediate cessation of the ability to perform its required function

NOTE Non-critical failures can be categorized as "degraded" (3.7) or "incipient" (3.26).

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3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

Failure definitions and nomenclature (According to ISO 14224)

degraded failure
failure that does not cease the fundamental function(s), but compromises one or several functions

NOTE 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.

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

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3.2 Evaluate equipment reliability and identify improvement opportunities

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Root Cause Failure Analysis

Failure definitions and nomenclature (According to ISO 14224)

3.17
failure data
data characterizing the occurrence of a failure event

3.18
failure impact
impact of a failure on an equipment's function(s) or on the plant

NOTE On the equipment level, failure impact can be classified in three classes (critical, degraded, incipient), see 3.6, 3.7 and 3.26). Classification of failure impact on taxonomy levels 3 to 5 (see Figure 3) is shown in Table 3.

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3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

Failure definitions and nomenclature (According to ISO 14224)

3.19
failure mechanism
physical, chemical or other process that leads to a failure

NOTE See also B.2.2.

3.20
failure mode
effect by which a failure is observed on the failed item

NOTE See also B.2.6.

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3.2 Evaluate equipment reliability and identify improvement opportunities

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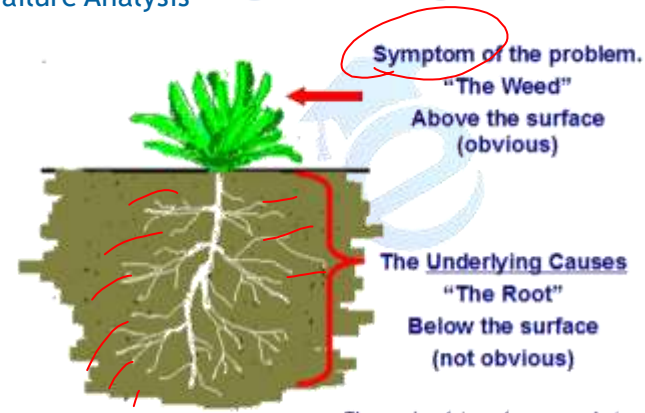
Root Cause Failure Analysis



The word root, in root cause analysis, refers to the underlying causes, not the one cause.

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3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

- "**Root cause analysis** (**RCA**) is a problem solving method aimed at identifying the root causes of problems or events.
- RCA is based on the belief that problems are best solved by attempting to address, correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms
- Applying corrective measures at root causes will prevent problem recurrence. However, it is recognized that complete prevention of recurrence by one corrective action is not always possible."

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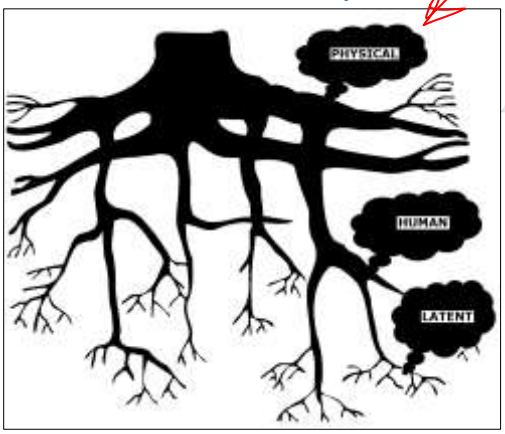
3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis



Root Causes

- Physical Roots – Tangible roots or component level roots. (Physical Root Causes are normally the first root causes uncovered.)
- Human Roots – Decision errors that result in omission or commission and almost always cause a Physical Root Cause to occur. This means they either did something wrong or did not do something they should have done
- Latent Roots – Organizational systems that people use to make decisions (for example, policies, procedures, instructions, etc.). When those systems have problems the result can be decision errors.

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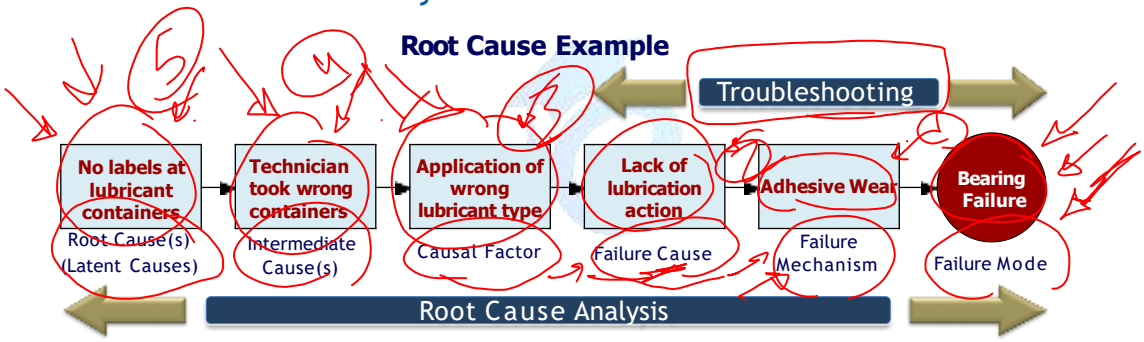
3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis



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3.2 Evaluate equipment reliability and identify improvement opportunities

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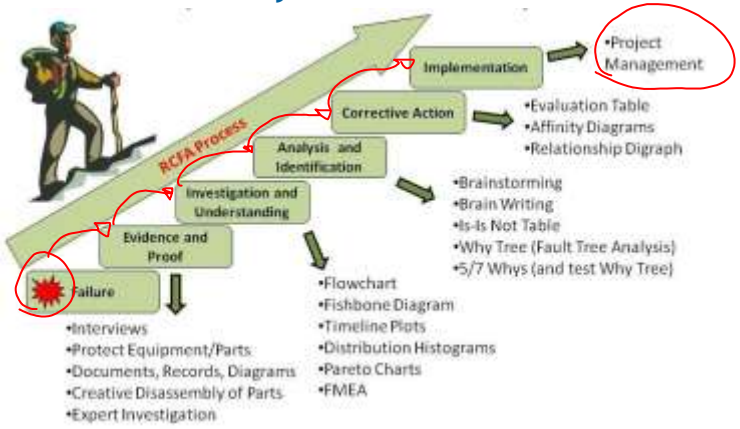
Root Cause Failure Analysis



Pillar 3 – Equipment Reliability

3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

- Troubleshooting ends at component level highlighting
  - ❖Primary failure – **what failed – component / system**
  - ❖Failure mode – **why failed - link between symptom and cause**
  - ❖Failure mechanism – **how failed - Science behind the failure**

- RCA leads to identification of Systemic Faults and their corrections
  - ❖RCFA
  - ❖Practices
  - ❖Human Factors
  - ❖Organization
  - ❖Environment

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3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

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Useful Tools For Determining Root Cause are:

- Brainstorming
- Failure Mode and Effect Analysis
- Pareto Analysis (Vital Few, Trivial Many)
- The "5 Whys"
- Fishbone (Ishikawa) Diagram
- Flow Charts / Process Mapping
- Cause and Effect Diagram
- Tree Diagram
- Event Charting and Causal Factor Analysis

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3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

Five Whys (5 Whys) for Root Cause Analysis

- **5 Whys** is an iterative question-asking technique used to explore the cause-and-effect relationships underlying a particular problem.
- The primary goal of the technique is to determine the root cause of a defect or problem by repeating the question "Why?"
- Each question forms the basis of the next question.
- The "5" in the name derives from an empirical observation on the number of iterations typically required to resolve the problem.

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3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

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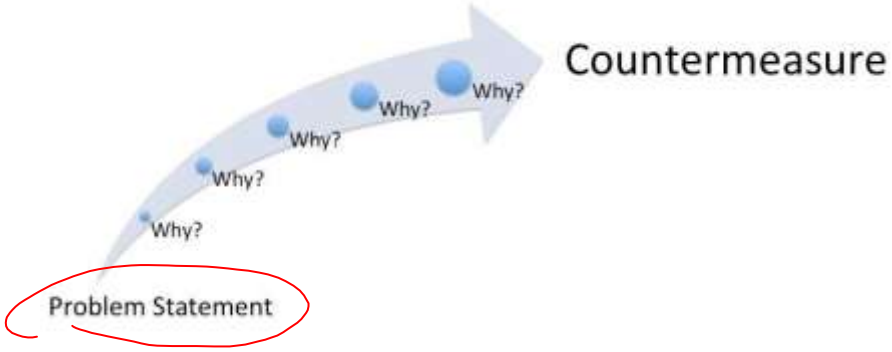
Five Whys (5 Whys) for Root Cause Analysis



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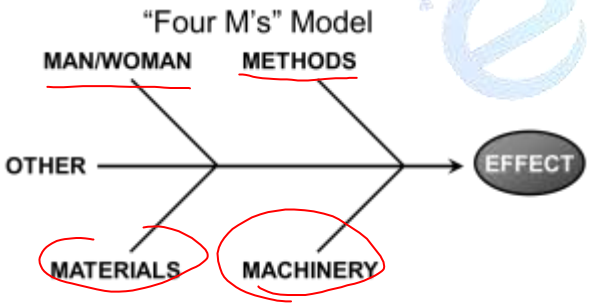
3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis

(Fishbone/Ishikawa Diagrams)

CAUSES (METHODS) ⟶ EFFECT (RESULTS)



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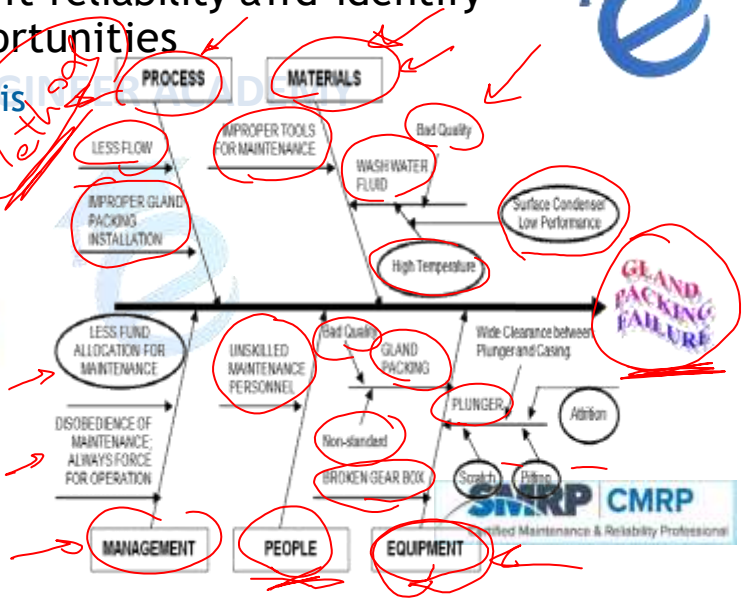
3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis



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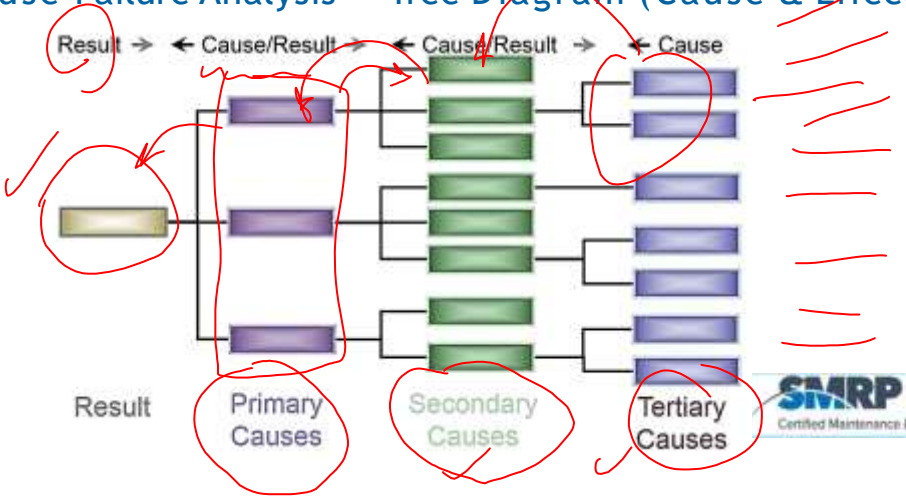
3.2 Evaluate equipment reliability and identify improvement opportunities

Root Cause Failure Analysis - Tree Diagram (Cause & Effect)



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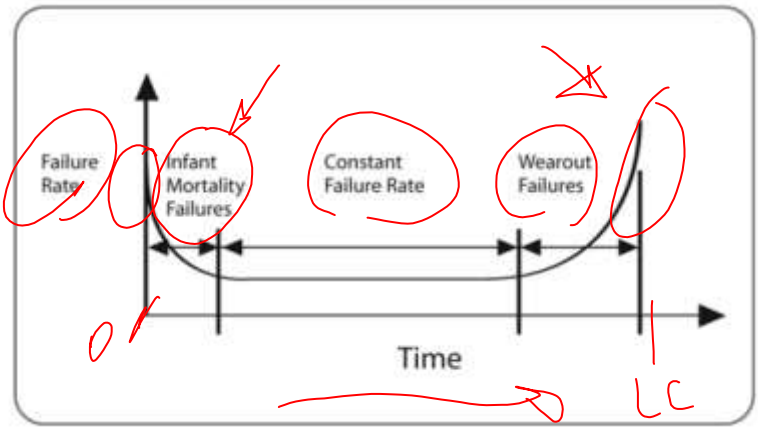
3.2 Evaluate equipment reliability and identify improvement opportunities

Failure Bath-Tub Curve



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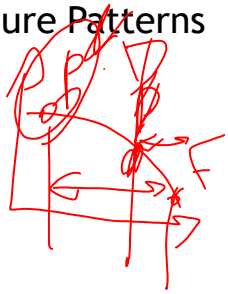
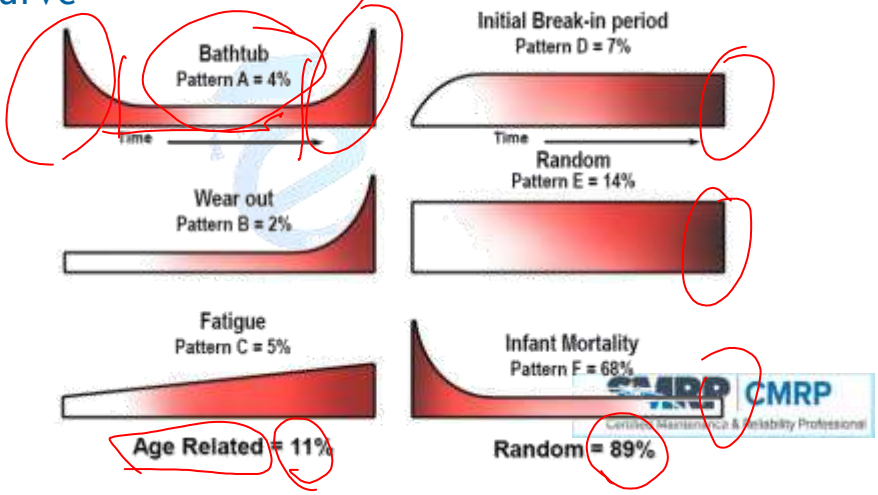
3.2 Evaluate equipment reliability and identify improvement opportunities

Failure Bath-Tub Curve

Failure Patterns





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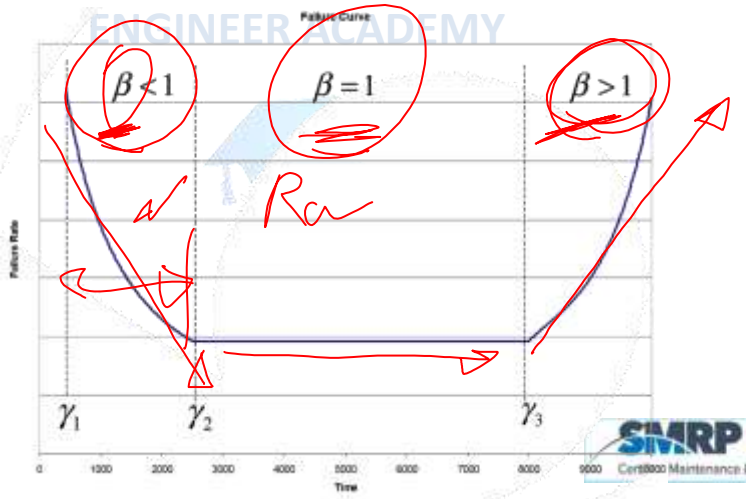
3.2 Evaluate equipment reliability and identify improvement opportunities

Weibull Analysis



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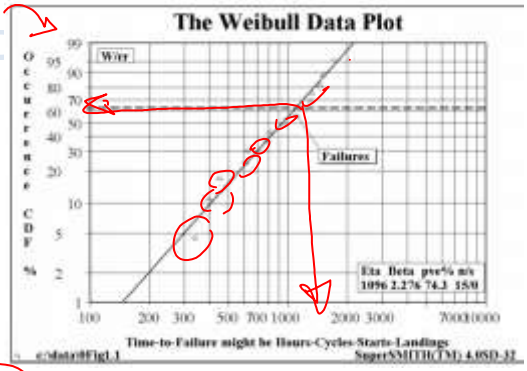
3.2 Evaluate equipment reliability and identify improvement opportunities

Weibull Analysis

The Weibull Analysis procedure is designed to fit a Weibull distribution to a set of n observations. It is commonly used to analyze data representing lifetimes or times until failure.



The horizontal scale is a measure of life or aging. Start/stop cycles, mileage, operating time, landings or mission cycles are examples of aging parameters.

The vertical scale is the cumulative percentage failed.

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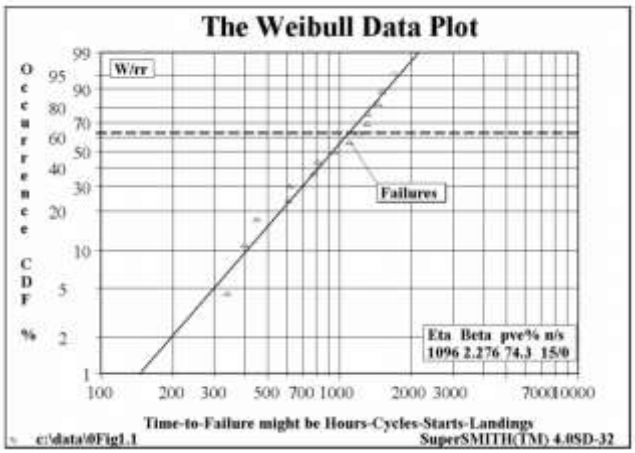
3.2 Evaluate equipment reliability and identify improvement opportunities

Weibull Analysis



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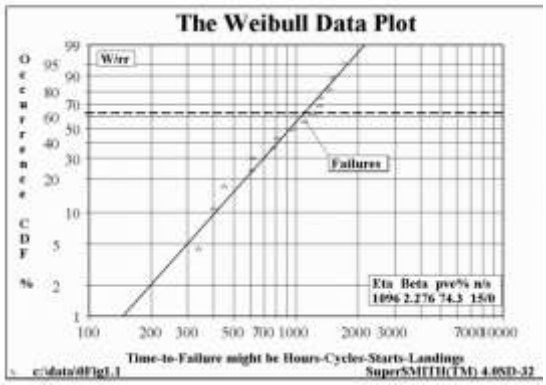
3.2 Evaluate equipment reliability and identify improvement opportunities

Weibull Analysis

The two defining parameters of the Weibull line are the slope, beta, and the characteristic life, eta. The slope of the line, β , is particularly significant and may provide a clue to the physics of the failure.



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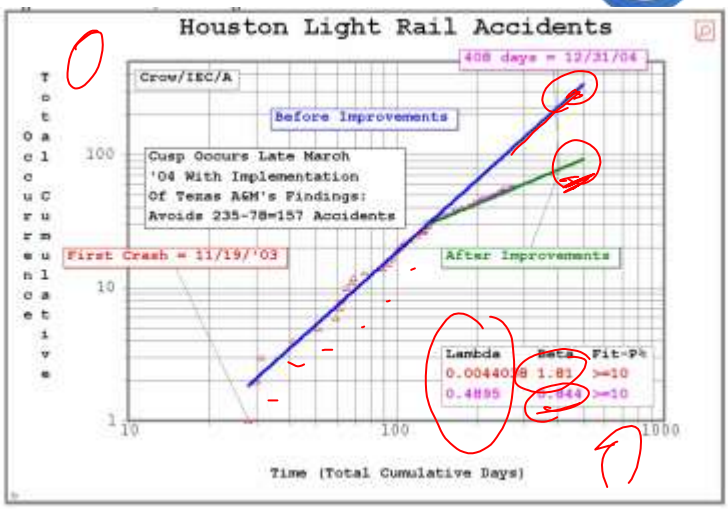
3.2 Evaluate equipment reliability and identify improvement opportunities

Weibull Analysis

- β < 1.0 indicates infant mortality
- β = 1.0 means random failures (independent of age)
- β > 1.0 indicates wear out failures



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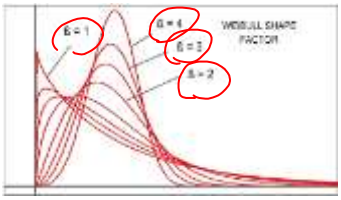
3.2 Evaluate equipment reliability and identify improvement opportunities

Weibull Analysis



The primary advantage of Weibull analysis is the ability to provide reasonably accurate failure analysis and failure forecasts with extremely small samples.

Another advantage of Weibull analysis is that it provides a simple and useful graphical plot of the failure data.

Question 1
Which of the following is the **primary purpose** of calculating Mean Time Between Failures (MTBF) for critical equipment?
To determine spare parts inventory levels
To measure average uptime and reliability performance
To identify operator training needs
To schedule preventive maintenance tasks

Correct Answer: B

Question 2
When analyzing failure data, which statistical tool is most appropriate for identifying whether failures follow a random pattern or are influenced by specific causes?
Pareto chart
Weibull analysis
Fishbone diagram
Control chart
Correct Answer: B

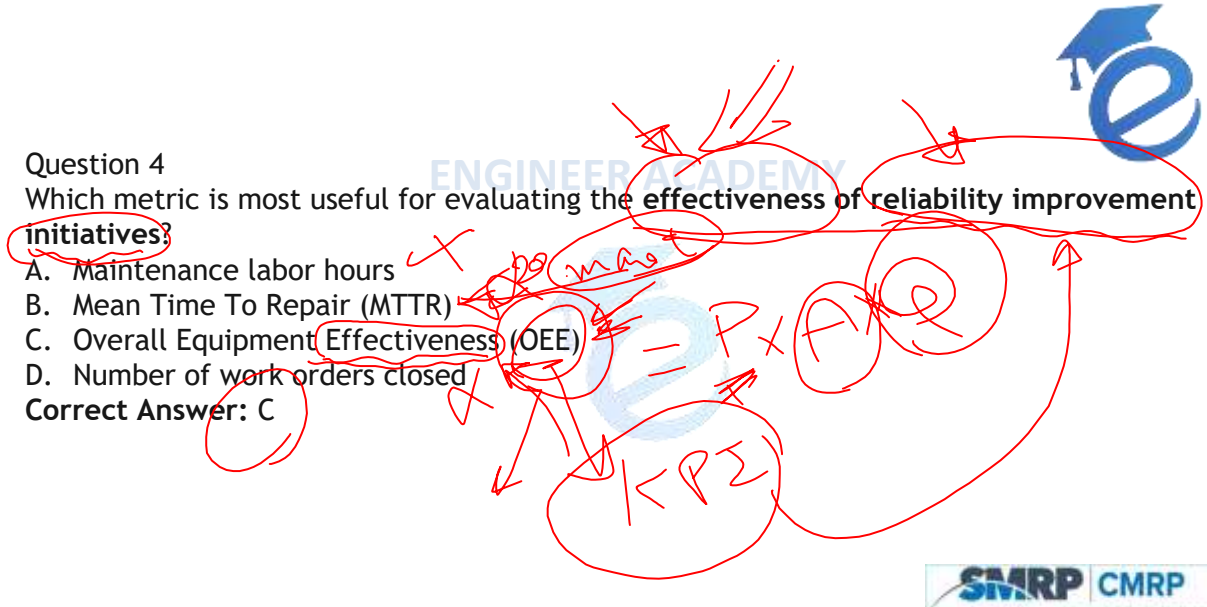
Question 3
A plant's centrifugal pump shows frequent seal failures. Reliability engineers recommend root cause analysis. Which improvement opportunity aligns best with Pillar 3 objectives?
A. Increase preventive maintenance frequency
B. Replace seals with upgraded material and redesign flush plan
C. Train operators on pump startup procedures only
D. Stock additional spare seals to reduce downtime
Correct Answer: B

Question 4

Which metric is most useful for evaluating the **effectiveness of reliability improvement initiatives**?

A. Maintenance labor hours
B. Mean Time To Repair (MTTR)
C. Overall Equipment Effectiveness (OEE)
D. Number of work orders closed

Correct Answer: C

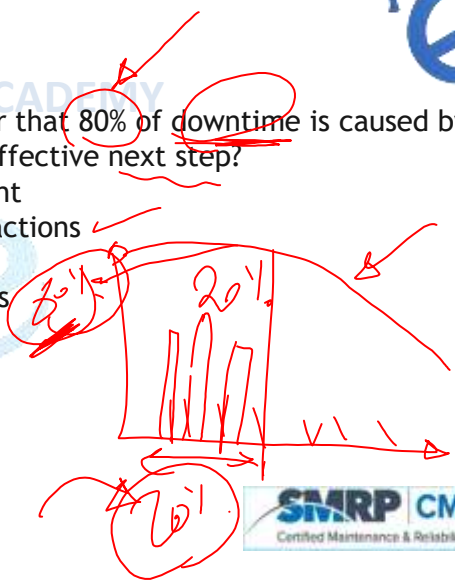


Question 5

During a reliability assessment, engineers discover that 80% of downtime is caused by three recurring failure modes. What is the most effective next step?

A. Increase inspection frequency for all equipment
B. Apply Pareto analysis to prioritize corrective actions
C. Replace all equipment with newer models
D. Focus only on reducing MTTR for minor failures

Correct Answer: B



Pillar 3 – Equipment Reliability

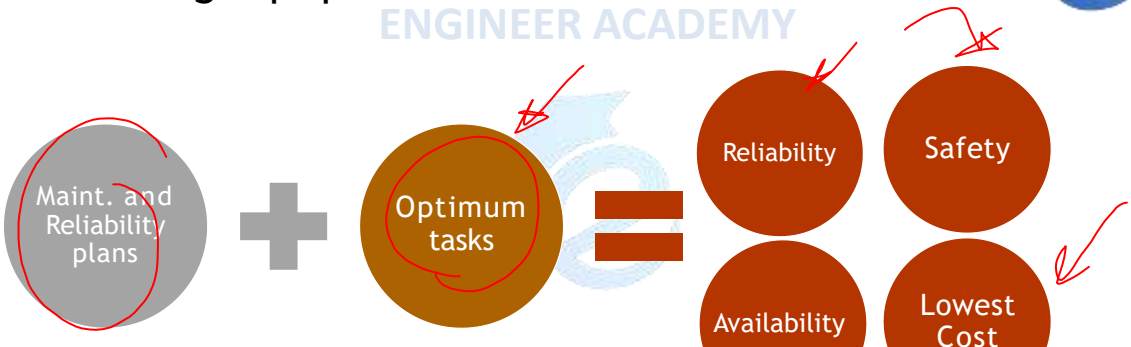
3.3 Establish a strategic plan to assure reliability of existing equipment

- Identify appropriate analysis techniques
- Develop maintenance strategy and tactics

Pillar 3 – Equipment Reliability

3.3 Establish a strategic plan to assure reliability of existing equipment

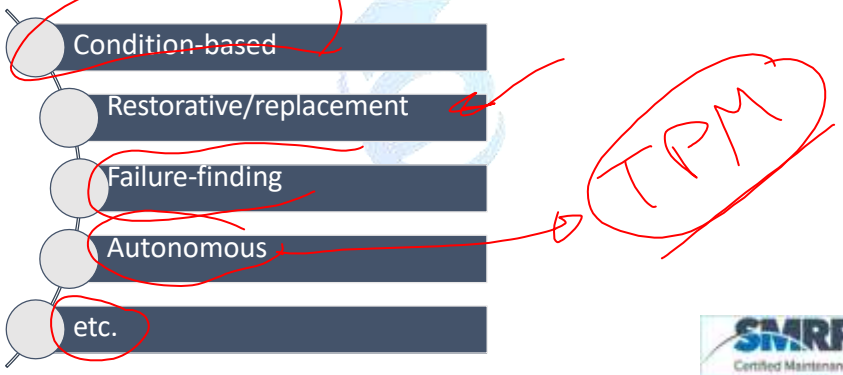
ENGINEER ACADEMY



Pillar 3 – Equipment Reliability

3.3 Establish a strategic plan to assure reliability of existing equipment

Maintenance activity types :



Pillar 3 – Equipment Reliability

3.3 Establish a strategic plan to assure reliability of existing equipment

ENGINEER ACADEMY

Maintenance activity types :

- Time Directed (TD) tasks, (Calendar (run time based PMs)
  - scheduled restoration tasks
  - scheduled discard tasks
- Condition Directed (CD) tasks, (CBM/PdM tasks) (scheduled on-condition tasks).
- Failure Finding (FF) tasks (operator supported tasks)
- Run-to-Failure (RTF) tasks (economical decision based)

Pillar 3 – Equipment Reliability

3.3 Establish a strategic plan to assure reliability of existing equipment

- For condition-based tasks to be applicable:
  - it must be able to detect the potential failure condition.
  - And there must be a reasonable, consistent amount of time between the first indication of potential failure and the actual failure.
- For time based overhaul tasks:
  - There must be an identifiable age at which the component fails.
  - And it must be possible to restore the original failure resistance through rebuilding or overhaul
- For failure finding tasks:
  - The equipment must be subject to a failure mechanism that is not evident to personnel during normal operation.

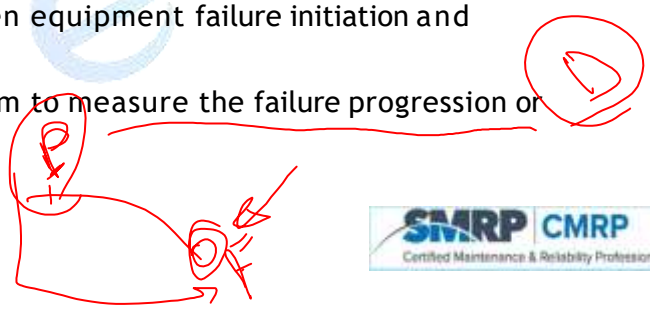
Pillar 3 – Equipment Reliability

3.3 Establish a strategic plan to assure reliability of existing equipment

ENGINEER ACADEMY

Task frequency can be summarized in the following questions:

1. How frequently does the failure mechanism that the task is aimed to address occur?
2. How much time elapses between equipment failure initiation and functional failure?
3. Is there an adequate mechanism to measure the failure progression or component degradation?



Pillar 3 – Equipment Reliability

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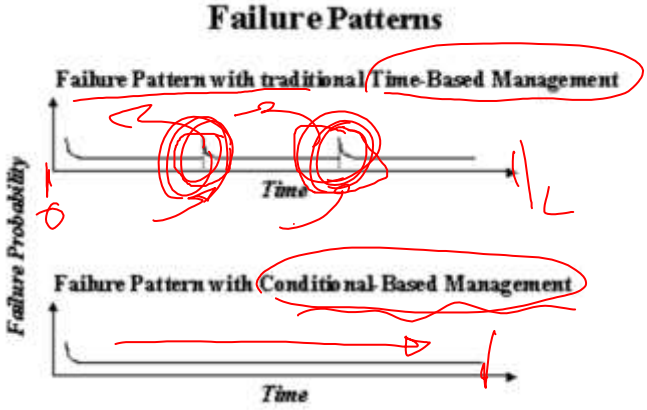
Defining Task Interval:



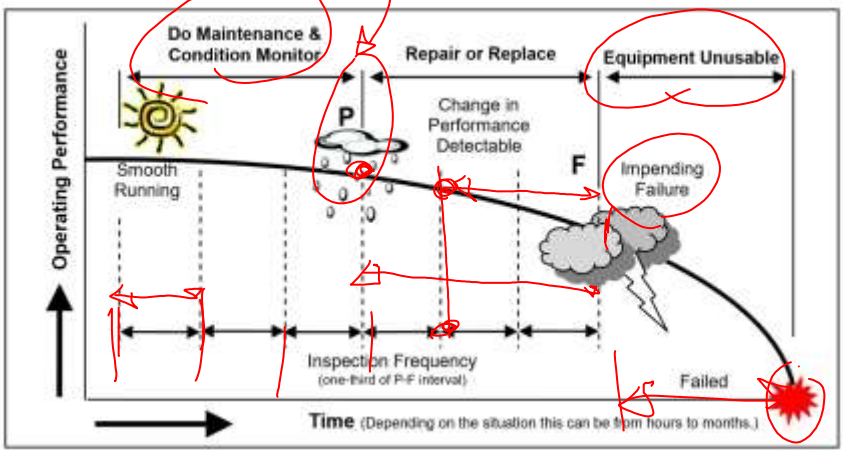
Pillar 3 – Equipment Reliability

3.3 Establish a strategic plan to assure reliability of existing equipment

ENGINEER ACADEMY

Defining Task Interval:

Condition Based Tasks:

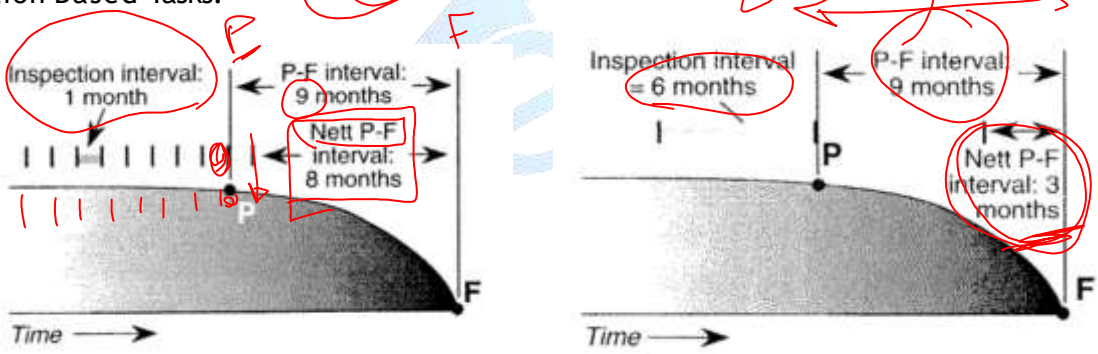


Pillar 3 – Equipment Reliability

3.3 Establish a strategic plan to assure reliability of existing equipment

Defining Task Interval:

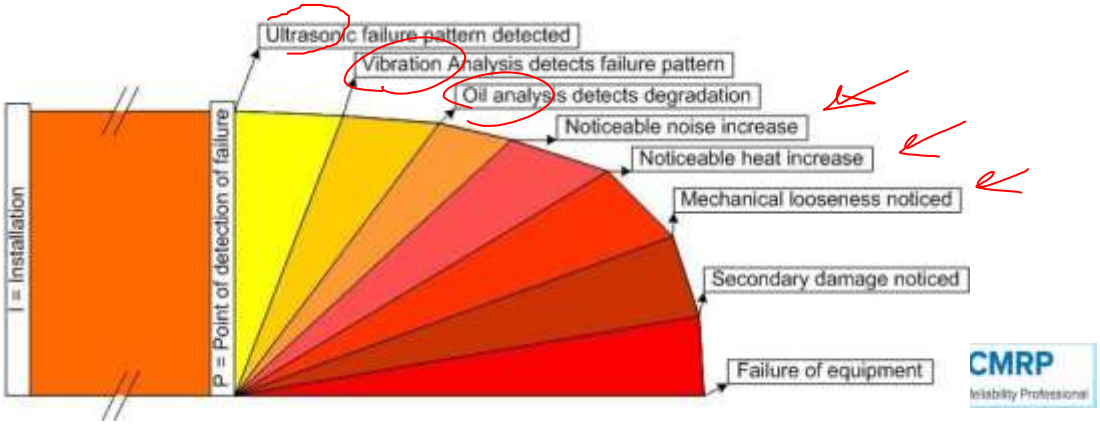
Condition Based Tasks:



Pillar 3 – Equipment Reliability

3.3 Establish a strategic plan to assure reliability of existing equipment

Maintenance Activity Types: Condition Based Maintenance



Pillar 3 – Equipment Reliability

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Maintenance Activity Types: Condition Based Maintenance