By failing to prepare, you are preparing to fail.
Benjamin Franklin "

Reliamaint Services

Asset Reliability Maintenance Management workshop

By Neeraj Kumar

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Workshop Objective

- To understand the equipment maintenance in holistic perspective
- To understand various elements of Asset Management
- To understand the relation between Maintenance, Reliability and Asset Management
- See the big picture (line of sight between maintenance goals and business objectives)
- How to develop and deploy asset maintenance strategy
- To understand the asset lifecycle cost, maintenance cost, direct and indirect cost
- Apply principles of RCFA , FMEA and RCM
- To understand principles of maintenance planning and scheduling
- Apply spare parts management and inventory optimization techniques
- Asset performance and reliability performance indicators

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Objective of Equipment Maintenance

- Equipment Reliability
- Risk reduction
- Defect Elimination
- Least operating cost
- Maximum Production
- Failure Avoidance

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Machine Maintenance Practices

- **Break down maintenance: It is carried out when equipment stopped, or fault reported by production staff.**
- **Preventive Maintenance: Predetermine maintenance activities are carried out on equipment based on Calendar based, Uses, Hours, mileage basis**
- **Predictive Maintenance: The equipment condition or some function/performance parameter is monitored with predetermine frequency. Based on the value of parameter maintenance task are determined and carried out. Example : Temperature, Vibrations, Flow Monitoring**
- **Condition Based Maintenance : The maintenance tasks are determined and carried out based on observations of scheduled or ad-hoc inspections . They are also called corrective action**
- **Risk Based Inspections : Inspection scheduled based on equipment condition or perceived risk arise**
- **Opportunity Maintenance The planned task are scheduled based on availability of Equipment for Maintenance (product changeovers, non availability of raw material)**
- **Precision maintenance: Maintenance carried out on equipment in conformance with all technical standards applicable to the maintenance work e.g. Balancing Standard, Alignment Standards, leveling ,oil cleanliness Standards, Fits and Tolerance applicable, Tightening Torques Values Geometric tolerances, Storage and preservation standards are some example of Precision standards.**
- **Proactive maintenance All Activities carried out to modified or redesign the equipment function are termed as proactive maintenance. Such need arises out of Reliability Centered Maintenance , Root Cause Analysis**

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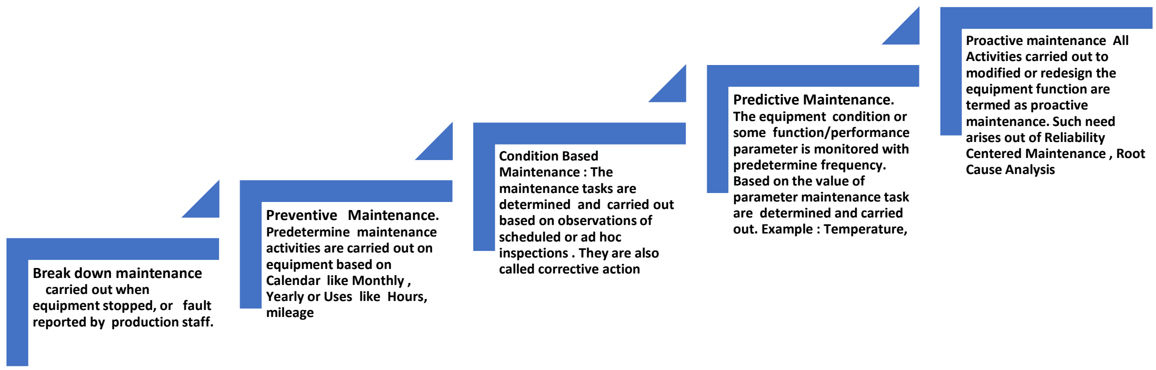
Machine Maintenance Practice Evolution



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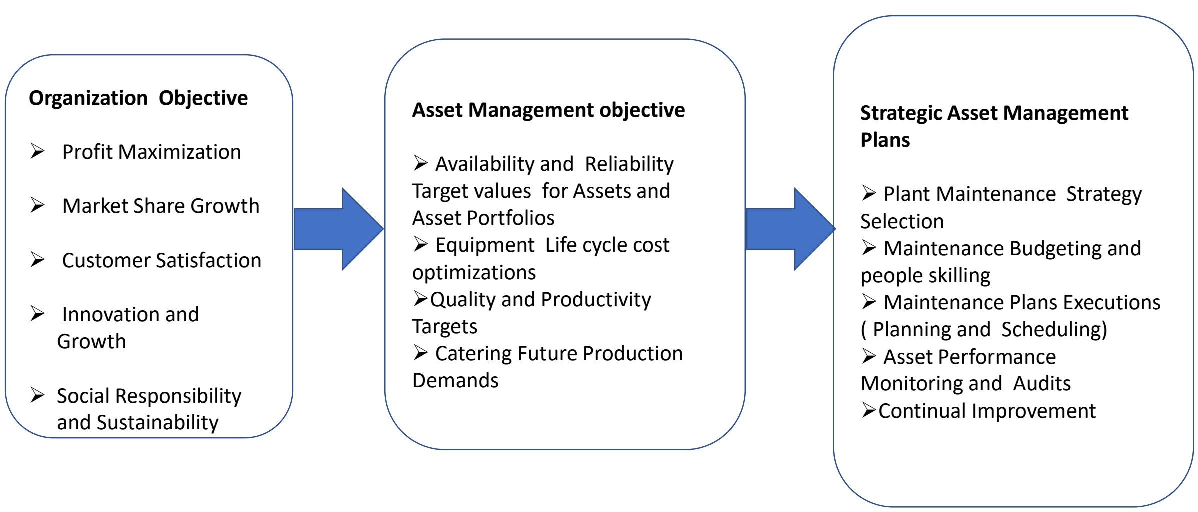
Maintenance Alignment with Organizational Objectives



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Maintenance Alignment with Organizational Objectives

Organization Objective

- Profit Maximization
- Market Share Growth
- Customer Satisfaction
- Innovation and Growth
- Social Responsibility and Sustainability

Asset Management objective

- Equipment Reliability
- Risk reduction
- Defect Elimination
- Least operating cost
- Maximum Production
- Failure Avoidance

Asset Management Tasks

- Break down Maintenance
- Corrective Maintenance
- Preventive Maintenance
- Predictive maintenance
- Proactive Maintenance
- Spare parts Management
- Maintenance Budgeting
- Manpower Budgeting and Skilling
- Asset Management Knowledge creation and Management

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Objective Hierarchies

Approach A

- ✓Equipment Reliability
- ✓Risk reduction
- ✓Defect Elimination
- ✓Failure Avoidance
- ✓Maximum Production
- ✓Least operating cost

- ✓ Systematic , They have overlapping work plans for time horizons.
- ✓ Drawing guidance from Lag and leading Key performance indicator. They are more in control of situations.
- ✓ Improved production

Approach B

- ✓Maximum Production
- ✓Least operating cost
- ✓Failure Avoidance
- ✓Risk reduction
- ✓Defect Elimination
- ✓Equipment Reliability

- ✓ Most of Maintenance is in form of Breakdown maintenance.
- ✓ Required to keep high inventory value for finish goods as well MROs
- ✓ Organizations are prone to incidents and accidents

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Big Picture

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Asset Management Frameworks

Frameworks are broad overview, outline, or skeleton of interlinked items which supports an approach to a specific objective, and serves as a guide.

Elements in Maintenance frameworks
- ✓ Organization Objectives
- ✓ Asset Management objective
- ✓ Asset Management Strategy and Plans
- ✓ Asset life cycles
- ✓ Support System , Skills, Resources, Information system
- ✓ Performance Review and Continual Improvement

Asset Management Frameworks
- ✓ ISO Standard 55000
- ✓ GRAFM Framework
- ✓ Uptime Framework
- ✓ Total Productive Maintenance (TPM)
- ✓ Reliability Centered Maintenance

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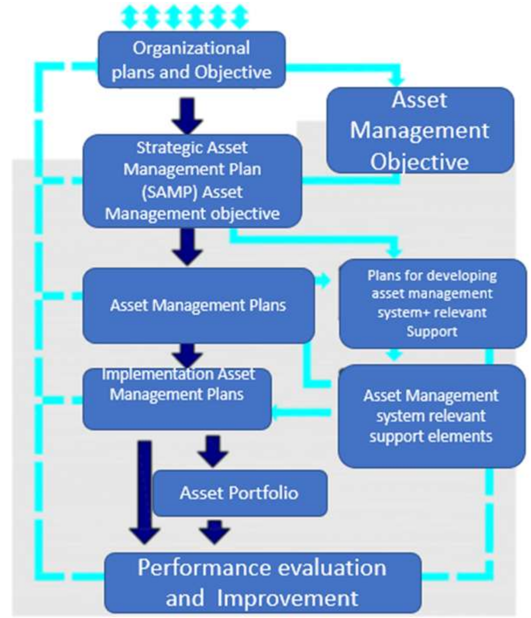
ISO Standard 55000

Fill this GAP



he grey highlighted box designates the boundary of the asset management system.

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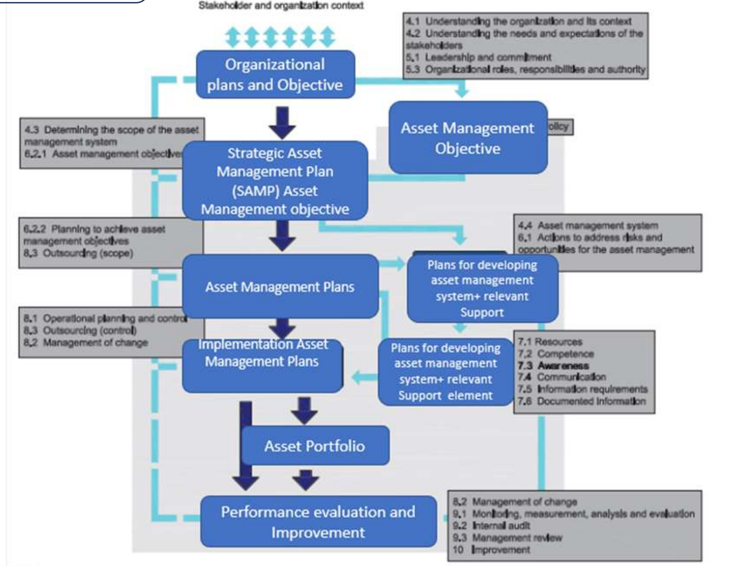
ISO Standard 55000



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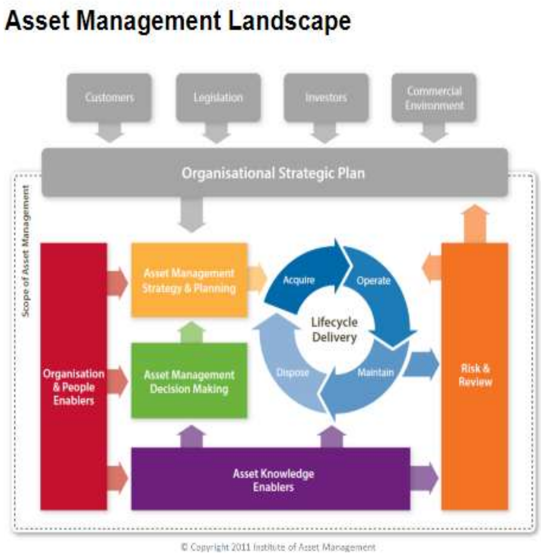
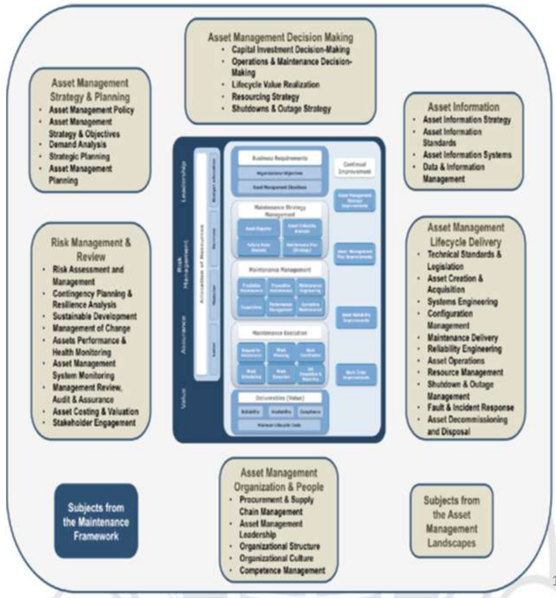
Global Forum on Maintenance and Asset Management





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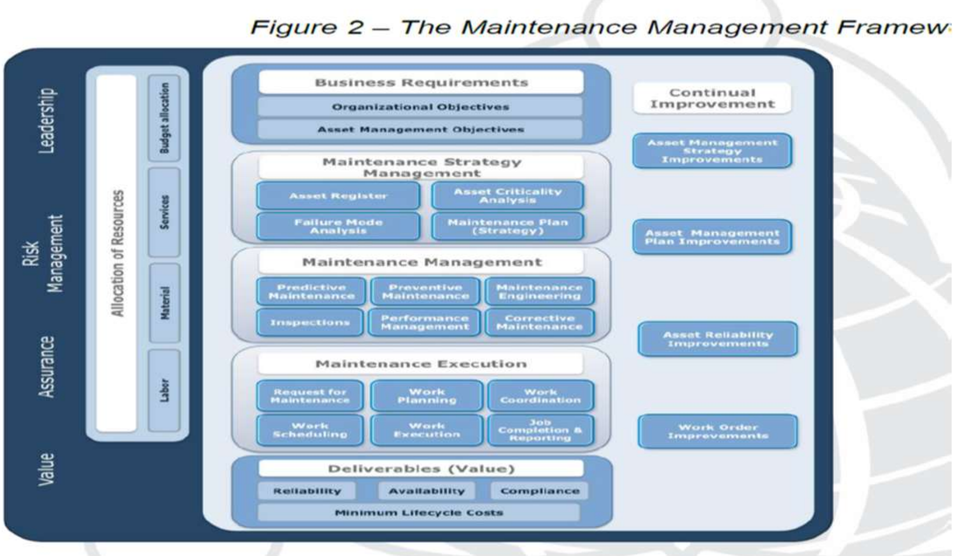
Global Forum on Maintenance and Asset Management

Figure 2 – The Maintenance Management Framew



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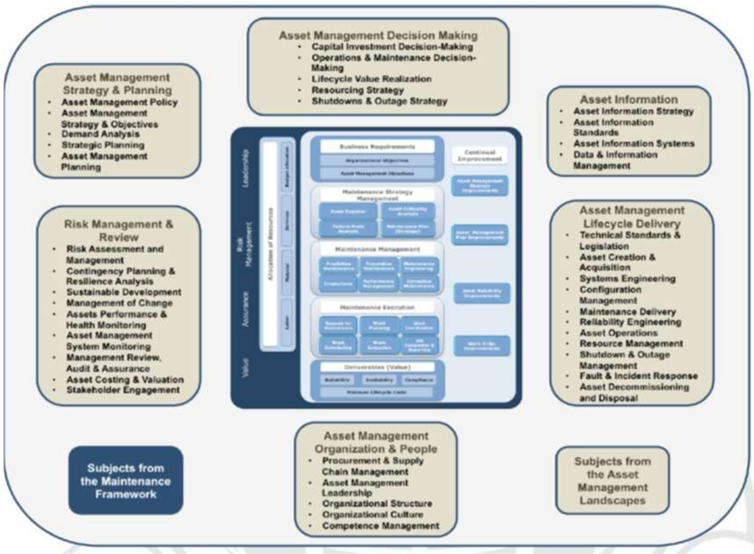
Global Forum on Maintenance and Asset Management



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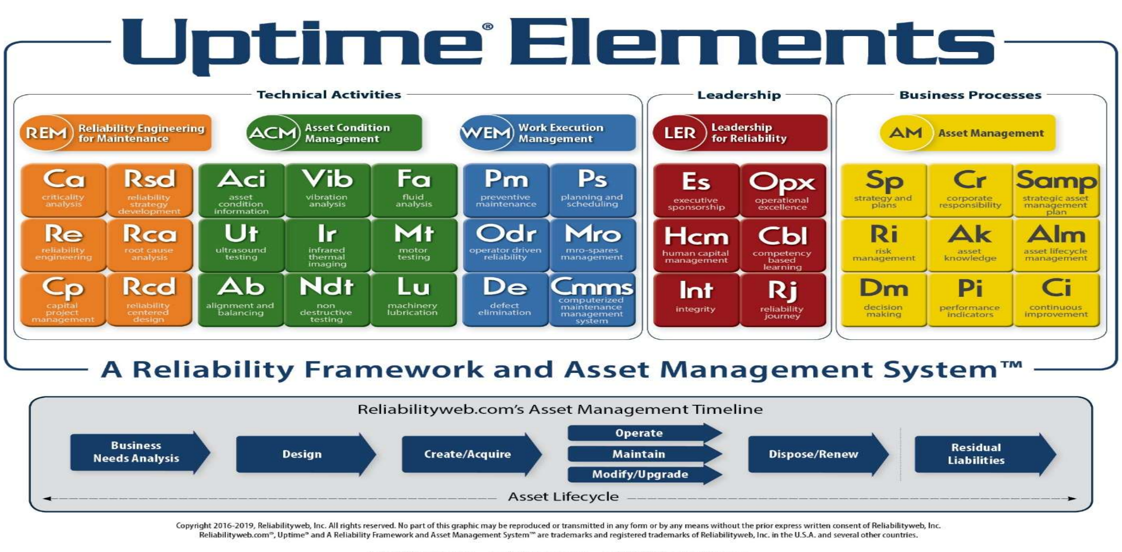
Uptime Reliability Framework



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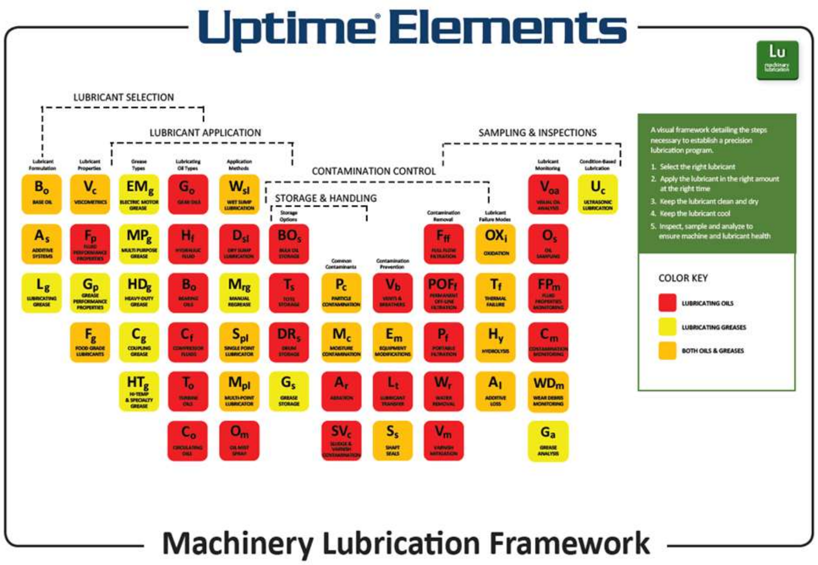
Uptime Reliability Framework



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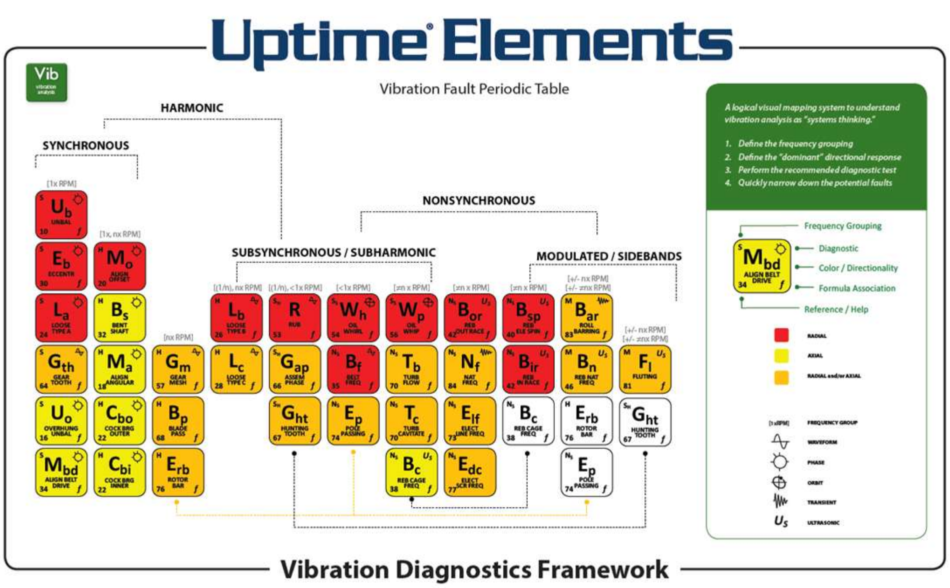
Uptime Reliability Framework



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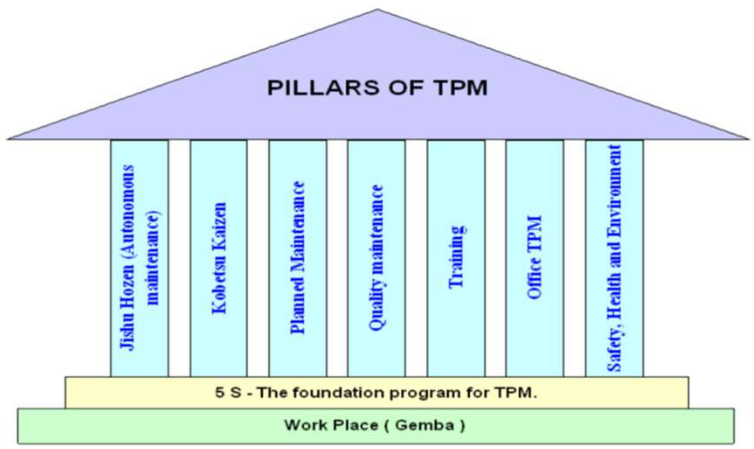
Total Productive Maintenance

Pillars of TPM:



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Total Productive Maintenance

TPM, or Total Productive Maintenance, is a comprehensive approach to equipment maintenance that aims to maximize the productivity and efficiency of manufacturing and production processes. TPM is built on several key pillars, each of which plays a crucial role in achieving its goals. These pillars are:

Autonomous Maintenance (Jishu Hozen): In this pillar, operators take responsibility for basic maintenance tasks on their equipment. This includes cleaning, inspection, lubrication, and small repairs. The goal is to prevent equipment deterioration and breakdowns, improving overall equipment effectiveness (OEE).

Planned Maintenance (Kikotei Hozen): This pillar focuses on proactive and planned maintenance activities. Maintenance tasks are scheduled in advance, and equipment is periodically inspected and maintained to prevent unplanned downtime and costly breakdowns.

Focused Improvement (Kaizen): Focused Improvement involves continuous improvement efforts to enhance equipment performance and overall process efficiency. This can involve identifying and eliminating sources of waste, reducing cycle times, and optimizing the production process.

Quality Maintenance (Hinshitsu Hozen): This pillar emphasizes the importance of preventing defects and maintaining consistent product quality. It involves addressing quality issues at their source and ensuring that equipment and processes contribute to producing high-quality products.

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Total Productive Maintenance

Education and Training (Kyojo Kaizen): TPM recognizes the importance of well-trained and skilled employees. This pillar focuses on providing training and development opportunities to equip employees with the knowledge and skills necessary to support TPM activities.

Early Equipment Management (EEM): EEM concentrates on designing, selecting, and installing equipment with a focus on maintainability and reliability. It ensures that equipment is capable of meeting production needs with minimal maintenance requirements.

Safety, Health, and Environment (SH&E): This pillar emphasizes the importance of maintaining a safe and environmentally friendly workplace. Safety and health standards are integrated into the maintenance and production processes, ensuring the well-being of employees and the environment.

Administration (Kobetsu Kaizen): TPM's administrative pillar involves establishing the systems and procedures necessary to support and sustain TPM activities. This includes record-keeping, documentation, and performance measurement.

TPM in Office (TBM - Total Business Management): TPM principles can also be extended beyond the shop floor to office and administrative processes. This pillar aims to improve the efficiency and effectiveness of administrative functions in an organization.

By implementing these pillars, TPM strives to create a culture of continuous improvement, reduce equipment downtime, enhance product quality, and boost overall operational efficiency. It's a holistic approach that involves all employees in the organization and fosters a sense of ownership and responsibility for equipment and process performance.

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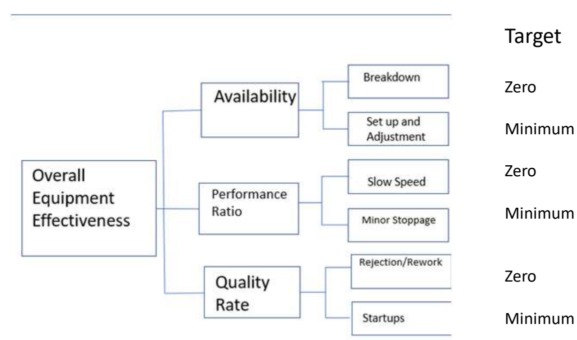
Overall Equipment Effectiveness Model



OEE=A x PE x Q

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RCM Evolution

Handbook on maintenance evaluation and program development, drafted by a Maintenance Steering Group formed to oversee development of the initial program for the new Boeing 747 airplane. This document, known as MSG-1,

Use of the decision-diagram technique led to further improvements, which were incorporated two years later in a second document, MSG-2, Airline Manufacturer Maintenance Program Planning Document. MSG -2 was used to develop the scheduled maintenance programs for the Lockheed 1011 and the Douglas DC1O airplanes.

In the 1970s, F. Stanley Nowlan and Howard F. Heap, two engineers at United Airlines, played a significant role in advancing RCM. Their research focused on optimizing the maintenance strategy for commercial aircraft, and their work led to the development of the RCM methodology

The Nowlan and Heap report provided the basis for MSG3 , which was promulgated in 1 980 and revised in 1 988 and 1 993. MSG3 remains to this day the process used to develop and refine maintenance program s for all major types of civil aircraft.

It's important to note that MSG-3 is a specific methodology used in the aviation sector RCM (Reliability-Centered Maintenance) is a broader concept applied across various industries, although they share similarities in their approach to maintenance optimization

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RCM Evolution

Introduction of John Moubray's RCM2 (1990s): John Moubray, a British engineer and author, introduced a widely recognized RCM methodology known as RCM2 in his book "Reliability-Centered Maintenance." RCM2 is a comprehensive approach that provides a structured framework for applying RCM principles in a variety of industries.

SAE JA1011 and SAE JA1012 (1990s): The Society of Automotive Engineers (SAE) published SAE JA1011, "Evaluation Criteria for RCM Processes," and SAE JA1012, "A Guide to the RCM Standard," in the 1990s. These standards provided guidelines and best practices for implementing RCM and assessing the effectiveness of RCM processes.

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Factor Leads to RCM Evolution

The traditional approach to scheduled maintenance programs was based on the concept that every item on a piece of complex equipment has a 'right age ' at which complete overhaul is necessary to ensure safety and operating reliability.

Many types of failures could not be prevented or effectively reduced by such maintenance activities, no matter how intensively they were performed.

In response to this problem, airplane designers began to develop design features that mitigated failure consequences - that is, they learned how to design airplanes that were failure tolerant '. Practices such as the replication of system functions, the use of multiple engines and the design of damage tolerant structures **greatly weakened the relationship between safety and reliability**, although this relationship has not been eliminated altogether

There was still a question concerning the relationship of preventive maintenance to reliability

Experience showing that it was not possible to control the failure rate of certain types of engines by any feasible changes in either the content or frequency of scheduled overhauls

Direct challenge to the traditional concept that length of time between successive overhauls of an items was an important factor in controlling its failure rate.

Scheduled overhaul has a little effect on the overall reliability of a complex Item unless the Item has a dominant failure mode

There are many items for which there is no effective form of scheduled maintenance

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RCM Benefits

The objective of the techniques outlined in MSG-l and MSG-2 was to develop a scheduled-maintenance program that assured the maximum safety and reliability of which the equipment was capable and also provided them at the lowest cost.

As an example of the economic benefits achieved with this approach, under traditional maintenance policies the initial programme for the Douglas DC-8 airplane required scheduled overhaul for 339 items, in contrast to seven such items in the DC-J 0 program

One of the items no longer subject to overhaul limits in the later programs was the turbine propulsion engine. Elimination of scheduled overhauls for engines led to major reductions in labor and materials costs, and also reduced the spare-engine inventory required to cover shop maintenance by more than 50%. Since engines for larger airplanes then cost more than US$l million each, this was a respectable saving.

As another example, under the MSG-1 program for the Boeing 747,United Airlines expended only 66 000 manhours on major structural inspections before reaching a basic interval of 20 000 hours for the first heavy inspections of this airplane. Under traditional maintenance it took an expenditure of more than 4 million manhours to arrive at the same structural inspection interval for the smaller and less complex

Such cost reductions are achieved with no decrease in reliability. On the contrary a better understanding of the failure process in complex equipment has actually improved reliability by making it possible to direct preventive tasks at specific evidence of potential failures

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Reliability Centered Maintenance

Reliability-Centered Maintenance (RCM)—Any RCM process shall ensure that all of the following seven questions are answered satisfactorily and are answered in the sequence shown as follows:

What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?

In what ways can it fail to fulfil its functions (functional failures)

What causes each functional failure (failure modes)?

What happens when each failure occurs (failure effects)?

In what way does each failure matter (failure consequences)?

What should be done to predict or prevent each failure (proactive tasks and task intervals)?

What should be done if a suitable proactive task cannot be found (default actions)?

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Top Management Responsibility for Asset Management

Engagement in setting the objectives and measures of success for the people responsible for the asset management system:

- by setting priorities for these objectives;
- by allocating appropriate resources for the achievement of these objectives;

Establishing a strong collaborative work culture that is focused on delivering the asset management objectives;

Determine asset management objectives and their alignment with the organizational objectives

Top management and leaders at all levels are responsible for ensuring that appropriate resources are in place to support the asset management system

Define Role , Responsibilities and Accountability in Asset Management organizational

Shall ensure its alignment to other management systems within the organization through appropriate organizational design

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Asset Management Policy

- The asset management policy is a short statement that sets out the principles by which the organization
- intends to apply asset management to achieve its organizational objectives
- The policy should set out the organization's commitments and expectations for decisions, activities and behavior concerning asset management
- Examples of asset management policy principles may include commitments for:
- Guiding principles for asset management activities, e.g. service delivery objectives are to guide asset management practices and decisions;
- Adherence to applicable laws, legislation and regulations;
- The provision of resources to deliver on asset management objectives and the structure or working of the organization to achieve the organizational objectives, e.g. asset planning and management is to be integrated with corporate and business planning, budgetary and reporting processes;
- The decision-making criteria to be used, e.g. asset management decisions are to be based on evaluations of alternatives that take into account life cycle costs, benefits and risks of the asset;
- Reporting on asset and asset management performance;
- Long-term objectives, sustainable outcomes and stakeholder requirements;
- Continual improvement of the asset management system

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Operational Risk Reduction

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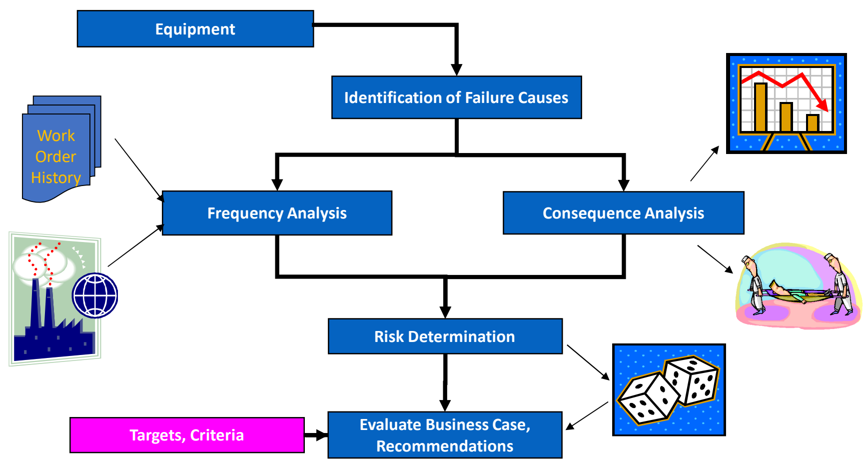
Classical Risk Analysis Method



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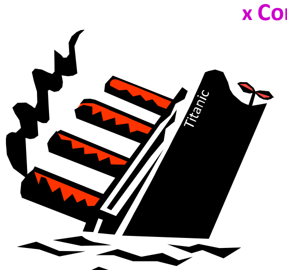
Understanding and Measuring Risk

Risk is the product of probability or likelihood that an event will happen and the cost if it does. It is a power law. Operating risk is the size of the financial loss that will be incurred from a failure during operation.

Risk ($/Yr) =
Frequency of Occurrence (events/Yr)
x **Consequence** of Occurrence ($/event)



Risk does not arise entirely randomly; rather it is affected by 'decision-makers' present in a system, usually we humans. It means the risk of catastrophic events occurs more often than by pure chance. In power-law-mirrored events a few factors have huge impacts, while all the numerous rest have little effect. For risk this means there are a few key factors that influence the likelihood of catastrophe. **Control these few factors and you increase the chance of success.** They are known as the critical success factors. You can identify them by asking, "What affects the ability to meet the objective?"

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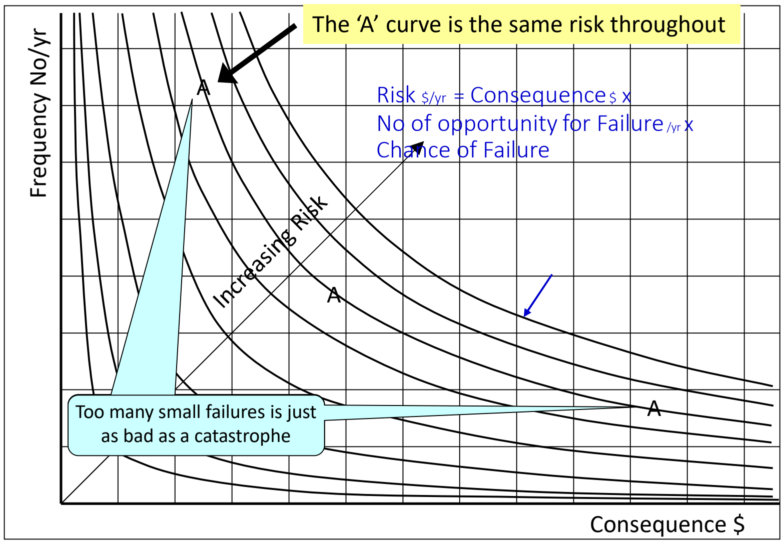
Risk can be Measured



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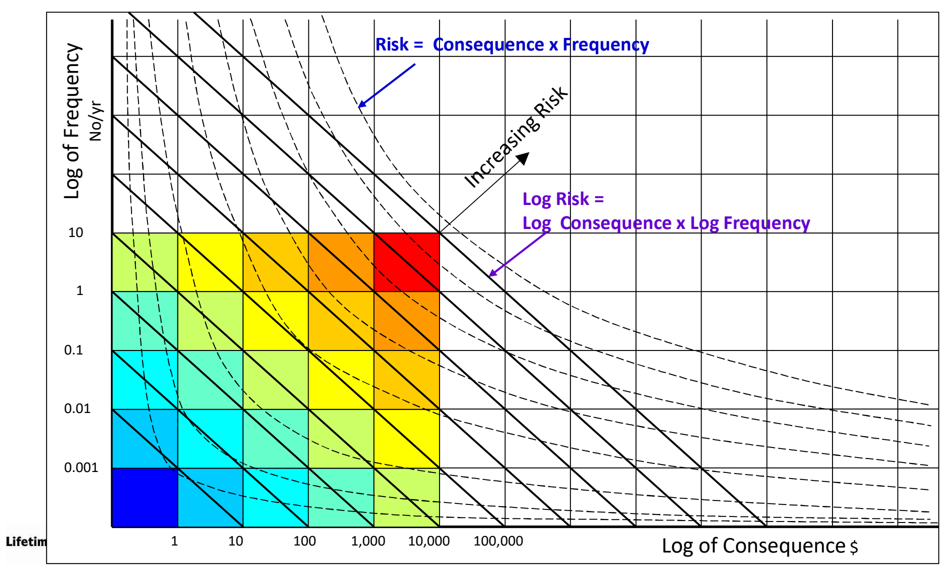
Grading Risk based on Chance & Consequence



www.lifetime-reliability.com

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Example of Using a Risk Boundary

- Return Roller Not Maintained

Likelihood of Failure Event per Year

Event Count per Year	Time Scale	Descriptor Scale	Historic Description	
100	Twice per week	Certain-immediate		L13
30	Once per fortnight	Certain-soon		L12
10	Once per month	Certain		L11
3	Once per quarter			L10
1	Once per year	Almost Certain	Event will likely occur on an annual basis	L9
0.3	Once every 3 years	Likely	Even has occurred several times or more in a lifetime career	L8
0.1	Once per 10 years	Possible	Event might occur once in a lifetime career	L7
0.03	Once per 30 years	Unlikely	Event does occur somewhere from time to time	L6
0.01	Once per 100 years	Rare	Heard of something like it occurring elsewhere	L5
0.003	Once every 300 years			L4
0.001	Once every 1,000 years	Very Rare	Never heard of this happening	L3
0.0003	Once every 3,000 years			L2
0.0001	Once every 10,000 years	Almost Incredible	Theoretically possible but not expected to occur	L1

DAFT Cost per Event	$30	$100	$300	$1,000	$3,000	$10,000	$30,000	$100,000	$300,000	$1,000,000	$3,000,000	$10,000,000	$30,000,000	$100,000,000	$300,000,000	$1,000,000,000
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16

Note:

Risk Level	
Red = Extreme	1) Risk Boundary is set at 'LOW' Level
Amber = High	2) Based on HB436:2004-Risk Management
Yellow = Medium	3) Identify 'Black Swan' events as B-S (A 'Black Swan' event is one that people say 'will not happen' because it has not yet happened)
Green = Low	4) DAFT Cost (Defect and Failure True Cost) is the total business-wide costs and lossses from the event
Blue = Accepted	

1Reliability

Risk = Consequence $ x [Frequency of Opportunity /yr x Chance of Opportunity becoming a Failure]

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Risk – Reduce Chance or Reduce Consequence?

Risk = Chance x Consequence

Chance Reduction Strategies	***Consequence Reduction Strategies***
• Engineering and Maintenance Standards • Failure Design-out Corrective Maintenance • Failure Mode Effects Criticality Analysis (FMECA) • Statistical Process Control • Hazard and Operability Study (HAZOP) • Root Cause Failure Analysis (RCFA) • Precision Maintenance • Hazard Identification (HAZID) • Training and Up-skilling • Quality Management Systems • Planning and Scheduling • Continuous Improvement • Supply Chain Management • Accuracy Controlled Enterprise SOPs (ACE 3T) • Design, Operation, Cost Total Optimisation Review (DOCTOR) • Defect and Failure True Cost (DAFTC) • Oversize/De-rate Equipment • Reliability Engineering	• Preventative Maintenance • Predictive Maintenance • Total Productive Maintenance (TPM) • Non-Destructive Testing • Vibration Analysis • Oil Analysis • Thermography • Motor Current Analysis • Prognostic Analysis • Emergency Management • Computerised Maintenance Management System (CMMS) • Key Performance Indicators (KPI) • Risk Based Inspection (RBI) • Operator Watch-keeping • Value Contribution Mapping (Process step activity-based costing) • Logistics, stores and warehouses • Maintenance Engineering
Done to reduce the chance of failure	Done to reduce the cost of failure

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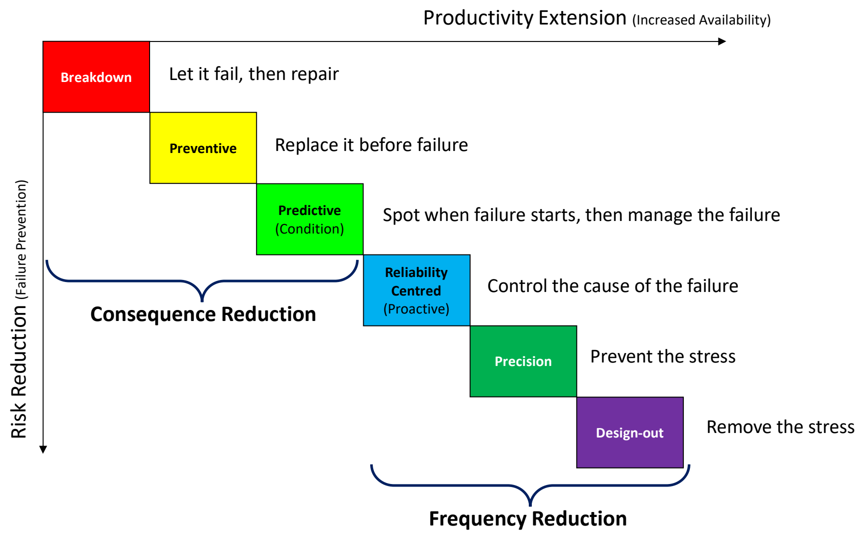
Risk and Maintenance Strategy Selection



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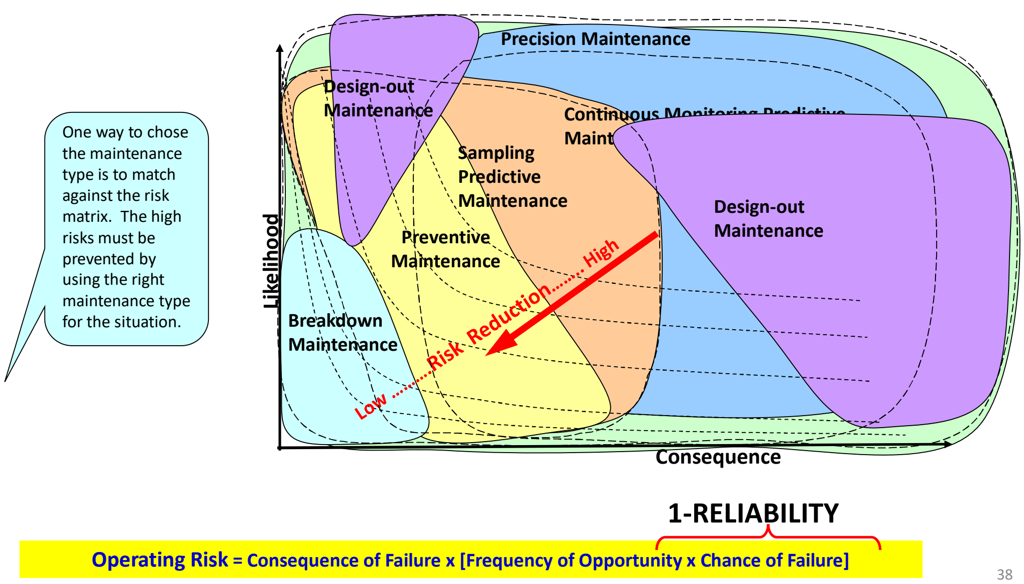
Match Maintenance Strategies to Risk



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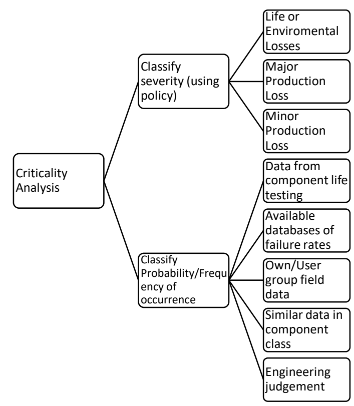
Equipment Criticality

- Risk = Failure Frequency/yr x TOTAL Cost Consequence ($)
- Equipment Criticality is used to identify operating equipment in priority order of importance to the continued operation of a facility.
- Those equipment items that stop the operation, or cause major costs if they fail, are identified as critical.
- The selection of appropriate means to prevent a failure can only be made when all the implications and knock-on effects are fully understood and appreciated.

Criticality Analysis



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Procedure For Critical Equipment

Risk Assessment and Prioritization:	•Identify critical equipment based on their impact on operations, safety, and overall business continuity. •Perform risk assessments to determine potential failure modes, consequences, and probabilities.
Condition Monitoring and Predictive Maintenance:	•Implement advanced condition monitoring technologies such as vibration analysis, thermal imaging, and oil analysis to detect early signs of equipment deterioration. •Utilize predictive maintenance algorithms to forecast potential equipment failures and schedule maintenance proactively.
Spare Parts Management:	•Maintain an inventory of critical spare parts, considering lead times, suppliers, and cost-effectiveness. •Implement a system for rapid spare part procurement to minimize downtime during critical equipment failures.
Reliability-Centered Maintenance (RCM):	•Apply RCM methodologies to determine the most suitable maintenance strategies for critical equipment, balancing cost, risk, and performance. •Regularly review and update maintenance plans based on changing operational conditions.
Emergency Response Planning:	•Develop contingency plans outlining immediate actions to be taken in case of critical equipment failures. •Train personnel on emergency procedures and ensure clear communication channels during crises
Redundancy and Failover Systems:	•Integrate redundancy and failover systems where feasible to ensure seamless operation even if a critical piece of equipment fails. •Regularly test and maintain redundant systems to ensure their readiness.
Lifecycle Management:	•Monitor and manage the entire lifecycle of critical equipment, from procurement to decommissioning. •Plan for timely upgrades or replacements to mitigate obsolescence risks.
Data Analytics and Performance Metrics:	•Implement data-driven approaches to monitor equipment performance and health in real-time. •Establish key performance indicators (KPIs) to track the reliability and availability of critical equipment.
Cross-Functional Collaboration:	•Foster collaboration between maintenance, operations, engineering, and management teams to ensure a holistic approach to critical equipment management. •Regularly share insights and updates on critical equipment performance across departments.
Documentation and Knowledge Management:	•Maintain up-to-date documentation for critical equipment, including operating procedures, maintenance history, and technical specifications. •Establish a knowledge sharing system to capture and transfer expertise related to critical equipment.
Continuous Improvement:	•Conduct regular reviews and analyses of critical equipment management processes to identify areas for improvement. •Implement lessons learned from past failures to enhance overall asset management strategies.

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Introduction to Reliability Engineering

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Reliability Engineering Terms

Function: *A verb-noun combination describing the purpose of a design*

Requirement: *A function performing with a certain characteristic*

Failure: *Termination of the ability of an item to perform a required function*

Reliability is the **probability** that an item of plant will perform its **duty** without **failure** over a designated **time**

Reliability is the **chance** of completing the mission

Failure Mode (Dominant) : *Manner in which an item fails (theoretical focus, historic failure or experienced event). The effect that you see when an item fails. Failure modes can be electrical (open or short circuit, stuck at high), physical (loss of speed, excessive noise), or functional (loss of power gain, communication loss, high error level).*

Failure Mechanism: *The processes by which failure modes are induced. It includes physical, mechanical, electrical, chemical, or other processes and their combinations. Knowledge of failure mechanism provides insight into the conditions that precipitate failures.*

Reliability Modeling: The process of representing a system's failure behavior using mathematical or statistical models (e.g., Weibull, Exponential) to analyze and estimate its reliability over time.

Reliability Prediction: The estimation of a component's or system's reliability based on design data, historical performance, or failure rate information, often using standardized models or failure databases.

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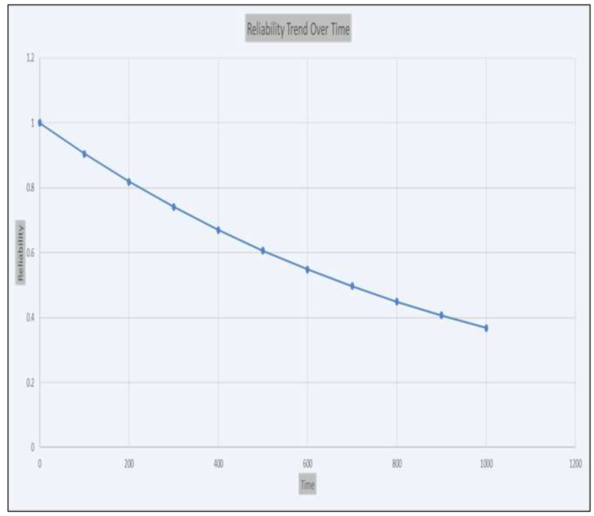
Reliability from MTBF (Exponential Model)

- Assumes constant failure rate (good for random failures)
- $R(t) = e^{(-\lambda t)}$ where λ =1/MTBF
- Example: If MTBF = 1000 hrs , R(100) = $e^{(100/1000)}$ ≈ 0.905
- Used for electronics or components with stable failure rates.



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Weibull Reliability Function

- R(t) = $e^{\left(-(t|\eta)^{\beta}\right)}$
- -η (eta): Scale parameter (characteristic life)
- - β (beta): Shape parameter
- Behavior based on β:
  - β < 1 → Infant mortality
  - β = 1 → Random failures (Exponential)
  - β > 1 → Wear-out failures

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Component vs System Reliability

- Component reliability is derived from behavior or data (MTBF, Weibull, etc.).
- System reliability depends on how components are arranged:
  - Series: all must work
  - Parallel: backup paths available
  - Series Parallel Combination
- System-level reliability is calculated from component models.

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Reliability of Series Systems

In a series arrangement it takes one component to fail and the whole 'system' is stopped. A series system always has less reliability than its least reliable component.

- Series Systems

→ 1 → 1 → 1 - - → n →

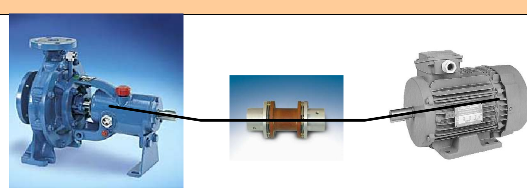
$R_{system} = R_1 \times R_2 \times R_3$

$= 0.95 \times 0.95$

$= 0.9025$

Number of Components	System Reliability
1	0.95
2	0.9025
4	0.8145
6	0.7351
8	0.6634
10	0.5987

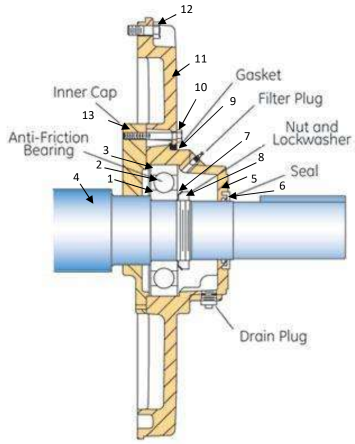
Notice the reliability falls as more items are added in series.

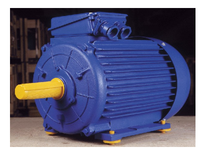


A pump set is a series arrangement of parts. The pump set will fail whenever any of its parts fail. It is no more reliable than the part with the worst reliability.

46

Machines are Arrangements of Parts





Electric motor drive end bearing

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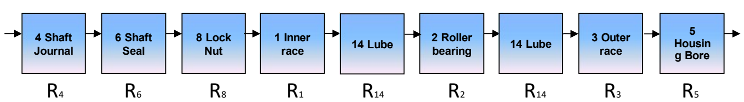
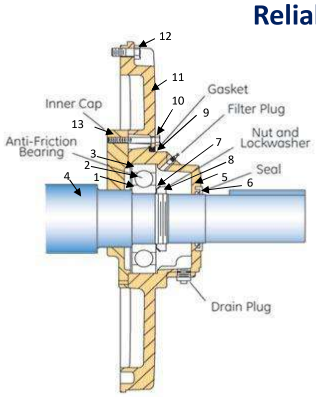
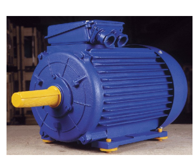
The Parts in our Machines Form a Series



Reliability: the chance of Success



Electric motor drive end bearing



1. For the motor to be highly reliable every bearing must be even more reliable.
2. For the bearing to be highly reliable each of its parts must be even more reliable.
3. ***For every part to be reliable its design and operating health must be risk-free.***

NOTE: R_n = Component reliability

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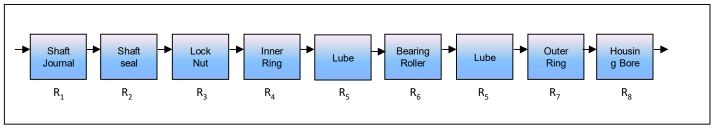
Calculating Equipment Reliability

Reliability is the **chance** that an item will last long enough to do its duty



$R_{series} = R_1 \times R_2 \times R_3 \times ... R_n$

R_{series} = 0.99 x 0.99 x 0.99 x 0.99 x 0.99 x 0.99 x 0.99 x 0.99 = $(0.99)^8$ = 0.92 (or 92%)

R_{series} = 0.99 x 0.99 x 0.99 x 0.99 x 0.5 x 0.99 x 0.5 x 0.99 x 0.99 = 0.23 (or 23%)

"Any poor, all poor"

R_{series} = 0.99 x 0.99 x 0.99 x 0.99 x 0 x 0.99 x 0 x 0.99 x 0.99 = 0

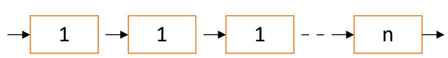
"Any fails, all fails"

49

Reliability Properties for Series Systems

The mathematics can be difficult. You won't need to do the math, but you need to know that such mathematics exists and be able to use the principles to optimise maintenance.

- Series Systems



$R_{system} = R_1 \times R_2 \times R_3 ... R_n$

R = 0.95 x 0.95 = 0.9025

Number of Components	Series System Reliability			
1	**0.95**	**0.97**	**0.99**	**0.9999**
2	0.9025	0.9409	0.9801	0.9998
4	0.8145	0.8853	0.9606	0.9996
6	0.7351	0.8330	0.9415	0.9994
8	0.6634	0.7837	0.9227	0.9992
10	0.5987	0.7374	0.9044	0.9990

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Reliability Properties for Series Systems

$R_{system} = R_1 \times R_2 \times \ldots R_n$

→ 1 → 1 → 1 - - → n →

Properties of Series Systems

1. ***The reliability of a series system can be no higher than the least reliable component.***
2. ***If 'k' more items are added into a series system of items (say 1 added to a system of 2, each with R = 0.9) the probability of failure of all items must fall an equal proportion (33%), to maintain the original system reliability.***
   (0.9 x 0.9 = 0.93 x 0.93 x 0.93 = 0.81)
3. ***A small rise in reliability of all items (say R of the three items rises 0.93 to 0.95, 2.2% improvement) causes a larger rise in system reliability (from 0.81 to 0.86, 5%).***

- Implications for Equipment made of Series Systems

•1 System-wide improvements lift performance higher than local improvements. This is why Planning, SOP's, training and up-skilling pay-off.

2 Improve the least reliable parts of the least reliable equipment first.

3 Carry spares for series systems and keep the reliability of the spares high.

4 Standardise components so fewer spares are needed.

5 Removing failure modes lifts system reliability. This is why Root Cause Failure Analysis (RCFA) and Failure Mode and Effects Analysis (FMEA) pay off.

•6 Provide pseudo-parallel equipment by providing tie-in locations for emergency equipment.

7 Simplify, simplify, simplify – fewer components means higher reliability.

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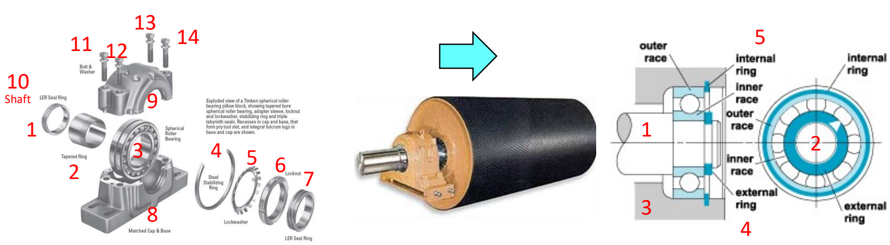
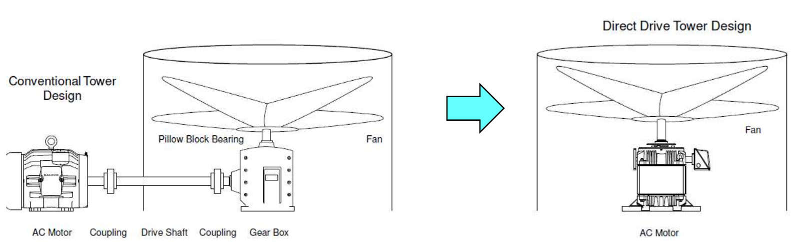
Simplify, Simplify, Simplify





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Reliability of Parallel Systems

In a parallel arrangement, even if one component fails, others do the work and the 'system' continues to operate. A parallel system is always more reliable than its most reliable component.

- Parallel Systems (Full active arrangement)

$R_{system} = 1-[(1- R_1)x(1- R_2)x \ldots (1-R_n)]$

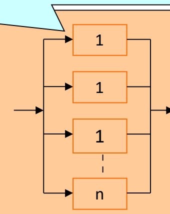
$= 1 – [(1-0.6) x (1-0.6)]$

$= 1 – [(0.4) x (0.4)]$

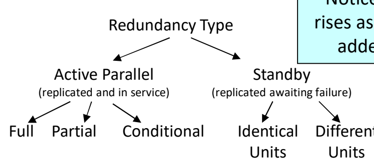
$= 1 – [(0.16)]$

$= 0.84$

Number of Components	System Reliability
1	0.6
2	0.84
4	0.9744
6	0.9959



Notice the reliability rises as more items are added in parallel.



This pump and filter arrangement is in stand-by parallel. One set can fail whenever any of its parts fail. But the other set is standing-by to takeover operation and continue running the process.

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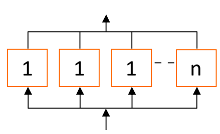
Reliability Properties for Parallel Systems

$R_{system} = 1-[(1- R_1)x(1- R_2)x \ldots (1-R_n)]$

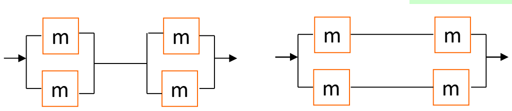


Properties of Parallel Systems

1. ***The more number of components in parallel the higher the system reliability.***
2. ***The reliability of the parallel arrangement is higher than the reliability of the most reliable component.***

- Implications of Parallel Systems for Equipment

1 Use parallel arrangements when the risk of failure has high DAFT Cost consequences.
2 Consider providing various paths for product to take in production plants with in-series equipment.
3 Build redundancy into your systems so there is more than one way to do a thing.



Which arrangement is more reliable if m = 0.9?
What percentage improvement is the more reliable?

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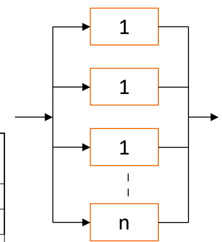
Reliability Properties for Parallel Systems

The mathematics can be difficult. You won't need to do the math, but you need to know that such mathematics exists and be able to use the principles to optimise maintenance.

- Parallel Systems

$R_{system} = 1-[(1- R_1) \times (1- R_2) \times (1-R_3) \dots (1-R_n)]$



Number of Components	Parallel System Reliability			
1	**0.6**	**0.8**	**0.9**	**0.99**
2	0.84	0.96	0.99	0.9999
4	0.9744	0.9984	0.9999	1.0000
6	0.9959	0.9999	1.0000	1.0000

R = 1 – [(10.6) x (10.6)] = 0.84

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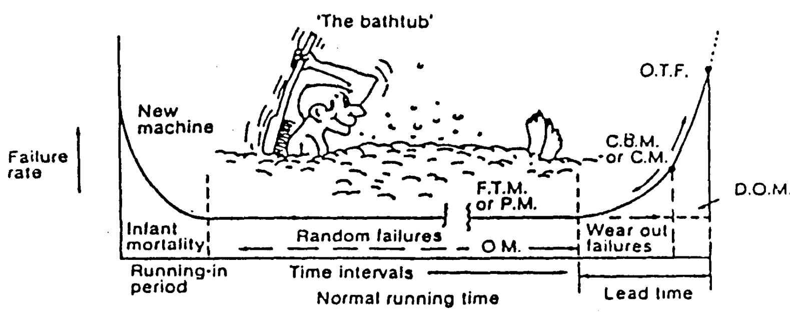
Traditional Bathtub Curve for Equipment

Traditional maintenance scheduling wrongly assumed "The *older equipment gets the more likely it is to fail."*



OTF -Operate to Failure
FTM – Fixed Time Maintenance
PM – Preventive Maintenance
CBM – Condition Based Maintenance
DOM – Design-Out Maintenance
OM – Operator Maintenance

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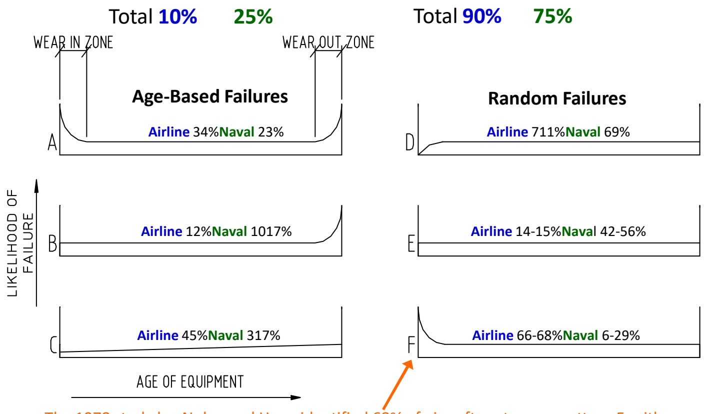
Individual Parts Reliability Curves

The Six Failure Curves and the Percentage of Component (i.e. parts) Types they Apply Too.



- The 1978 study by Nolan and Heap identified 68% of aircraft parts were pattern F, with high Infant Mortality and then random failures over time. We learnt that every time we do a repair we introduce a new chance of Infant Mortality
- Research by the USA merchant and military navy confirmed the presence of the failure patterns found in the aviation industry.

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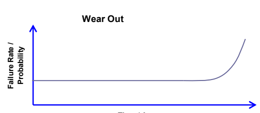
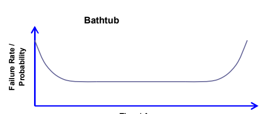
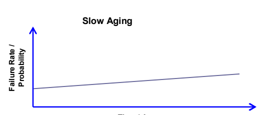
What the Reliability Curves A, B, C Mean



Wear Out (2%)
- Age related failures
- Constant or gradually increasing failure rate followed by pronounced wear out.
- Least common failure mechanism.
- Examples include reciprocating engines, pumps, liners.
- Routine maintenance based on time is effective.



The Bathtub (4%)
- High failure rate at beginning and end of life.
- Infant mortality followed by a constant failure rate and then pronounced wear out.
- Combination of maintenance tasks usually required.
- Examples include simple electro mechanical systems, solenoids.



Slow aging (5%)
- Gradually increasing failure rate.
- Associated with corrosion or creep.
- Generally process equipment in contact with the product.
- Rebuilds and component replacement tactics are effective.
- For example, turbines, pipes, refractory.

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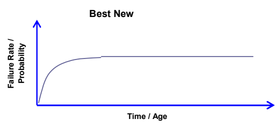
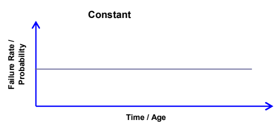
What the Reliability Curves D, E, F Mean



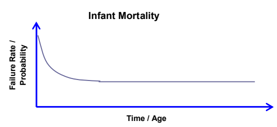
Best new (7%)

- •Only age related at the beginning of life.
- •A dominant increase in failure rate followed by a constant failure rate.
- •On condition is best maintenance approach.
- •For example, hydraulics and pneumatics.



Constant (14%)

- •These are random failures and are not age related.
- •A constant failure rate throughout the life of the component.
- •Routine age related maintenance is ineffective.
- •For example ball bearings, complex electronic and mechanical systems.



Infant Mortality (68%)

- •Most likely failure rate a component would have.
- •Infant mortality, a high failure rate reducing to a constant failure rate for remaining life.
- •Once infant mortality is resolved, routine maintenance is effective.
- •Examples include electronics and integrated equipment.

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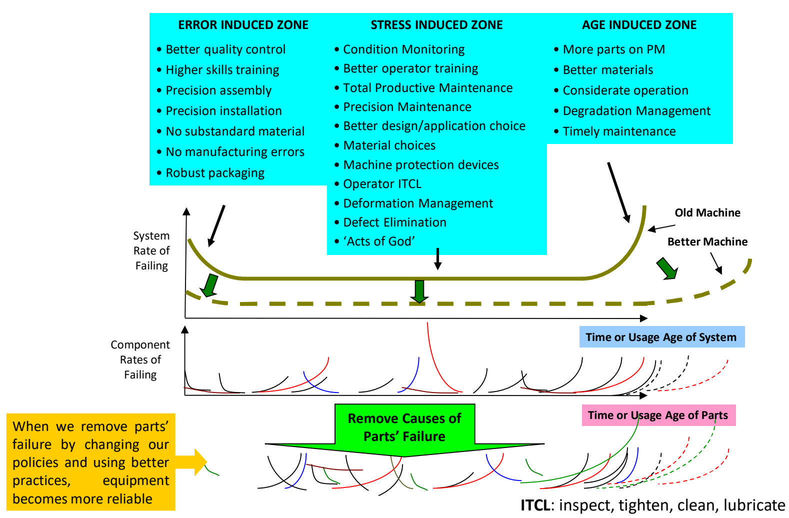
Equipment reliability is malleable by choice of policy and quality of practice.



ITCL: inspect, tighten, clean, lubricate

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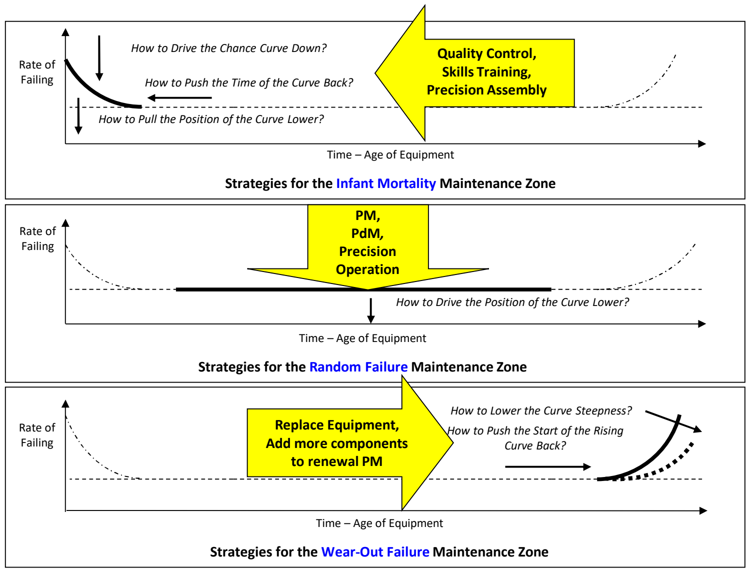
Equipment Reliability Strategies



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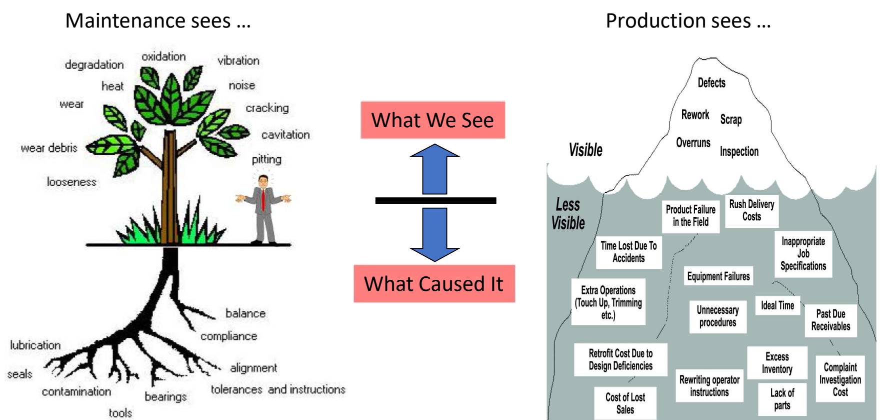
The Truth is Hidden Under the Surface



We see the high maintenance costs, scrap and late deliveries, but those are only the results of a sequence of events, they are not the real causes. Until we find and address the true root causes, there is no way to stop the poor results!

62

Life Cycle Asset Management

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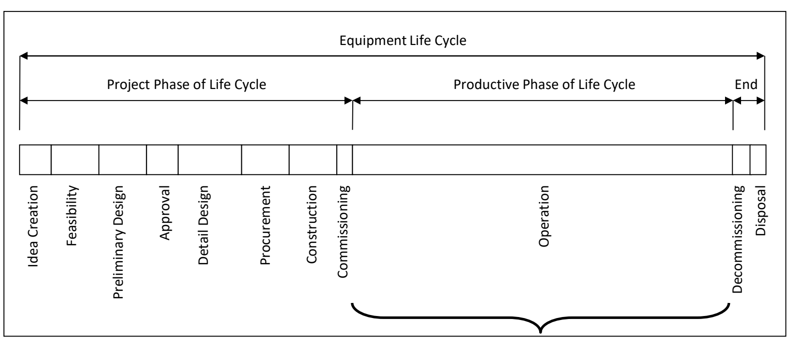
The Life Cycle of Plant and Equipment



Profits come from this stage of the life cycle, and are maximised when the operating costs are minimised.

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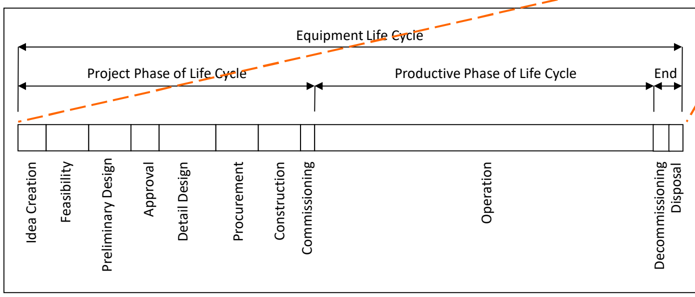
Manage the Plant and Equipment Life Cycle



To be sure we consider the long-term well-being of our business, we view the health of its plant and equipment from the end of their life cycle. We ask what do we do to get a long, healthy, problem-free operating life?

So by selecting methods and practices that lead to trouble-free operation, we're also maximising life cycle profit because there are far fewer (Defect and Failure True)DAFT Costs to pay for.

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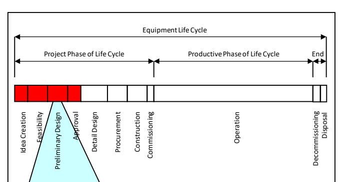
Feasibility and Financial Approval



Feasibility & Financial Approval

- Quality Function Deployment
- Engineering Standards/Guidelines
- Feasibility Costing Guidelines
  - Process and Instrumentation Diagrams (P&ID) 90% complete
  - Preliminary Design 50% complete
  - DAFT Costing
  - Life Cycle Cost Analysis
- Safety, Health & Environment Analysis
- Maintainability
- Operability
- Project/Financial Risk Analysis

The 'Operating Costs Committed' chart tells us that 70% of operating costs are set during this early stage of specifying the project. It's clear that in this very short period of time, when the blood rushes to peoples' heads, a great level of control over what they decide to do is needed.

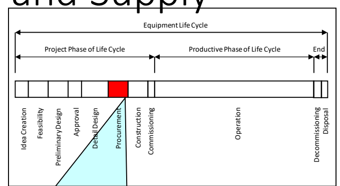
The only sure way to get prices within ± 30% is to get the P&ID 90% complete before you do the DAFT Costing and pricing take-off. If you want ± 10% cost accuracy you need to complete the P&ID's and do 50% of the final design.

66

Procurement and Supply

Procurement and Supply

- OEM Quality System Audit
- Engineering Standards
- Workshop Testing
- Storeroom Management for Reliability



This is the stage where we get defects coming into our business from the original equipment manufacturer (OEM). If they are no better than 2-1/2 to 3 sigma operators, you will get their quality problems to fix at some stage in the life of your plant.

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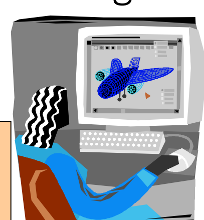
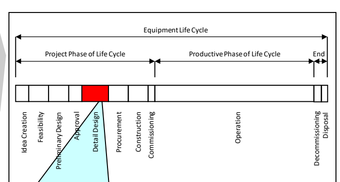
Detailed Design and Engineering

Detailed Design and Engineering

- Design Quality Management System
- Engineering Standards/Guidelines
- DOCTOR/DAFT Costing
- FMEA/RCM
- Life Cycle Cost Analysis
- Reliability Engineering
- Safety and Hazard Analysis
- Electrical System integrity/Safety
- Maintainability
- Risk Analysis
- Value Stream Improvement





We know from the nuclear industry report that 35% of plant and equipment problems will be generated at this stage of the life cycle. The operating risks are reduced when operations and maintenance are integrated with the designers, and their long-term needs allow the design to be optimised.

This one is particularly close to my heart – I just don't have the time and money to do a job twice, which should have been done right the first time.

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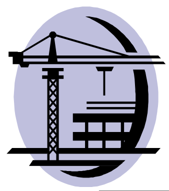
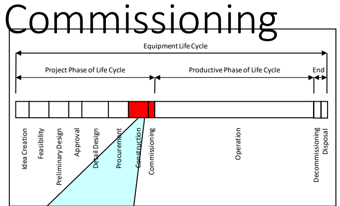
Construction and Commissioning





Construction & Commissioning

- Engineering Standards
- 3T Precision Installation Procedures
- Installation Quality Audits
- Rotating Equipment Integrity
- Project Planning
- Shutdown Planning
- Pre-commission/Commissioning Plan
- Occupational Health and Safety Plan
- Contractor Management

This is a critical period. All the best laid plans will come unglued at this stage if your equipment is installed distorted out-of-shape. A huge number of defects will be put onto your operation at this stage if your precautions are inadequate. Equipment installation must be done precisely and machines proven to be installed within specification.

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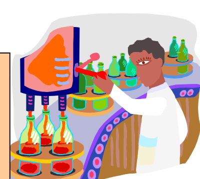
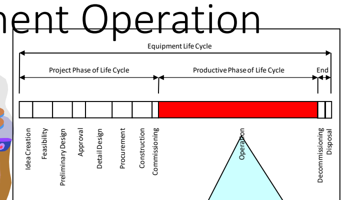
Plant and Equipment Operation





Plant & Equipment Operation

- Integrated Quality Management System
- 3T Operating Procedures
- 3T Maintenance Procedures
- Precision Maintenance
- Maintenance Planning & Scheduling
- Shutdown Planning
- Occupational Health and Safety
- Emergency/Disaster Management
- Lean Waste Reduction Principles
  - TPM/Operator Watch-keeping
  - 5S Workplace Discipline
  - Value Stream Analysis
- Rotating Equipment Integrity
- Lubrication/Wear Particle Management
- Predictive/Condition Monitoring
- Preventive Maintenance
- Opportunity Maintenance
- Energy Optimisation
- Training/Refresher Training
- Supply Chain Management
- RCFA/Six Sigma DMAIC
- HAZOP

For the entire operating life of your plant and equipment you want high plant reliability and availability. You will need to adopt excellent operating and maintenance practices. The 'human error rate' table makes it clear that we humans make mistakes. But we make far fewer mistakes when our processes and practices become simple and routine.

If we want to control the risk in 'human-dependent processes', it sounds like we will need ACE 3T procedures for all operations and maintenance work.

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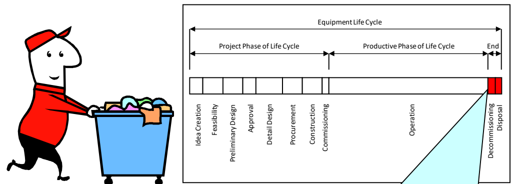
Decommissioning and Disposal

Decommissioning & Disposal

- Product Stewardship
- Legal Responsibility
- Statutory Requirements
- Geographic Location Selection
- Environmental Impact Modelling
- Safety Management Systems
- Plant Excursion Protection Systems
- Containment Systems
- Waste Management
- Emergency Response
- Operating Procedures
- Site Chemical Inventory



We don't want the huge cost and pain of repairing environmental damage. So we need to prevent the escape of all contaminants. Those that do get out by accident will need to be contained and treated.

There are legal and ethical requirements to meet. To manage this risk; prevention and containment needs to be designed into the plant and equipment. The consequences of any accidents will be managed through operating and emergency procedures.

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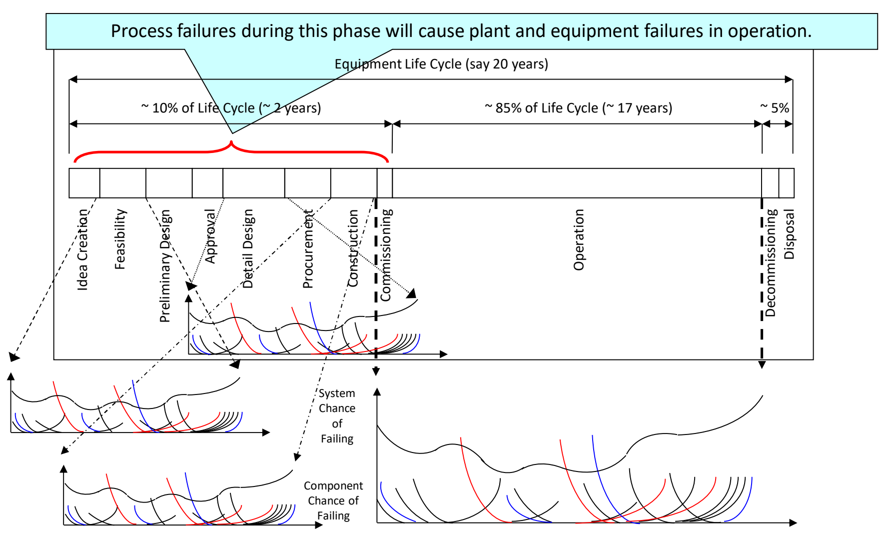
Effect of System Failures Across Life Cycle



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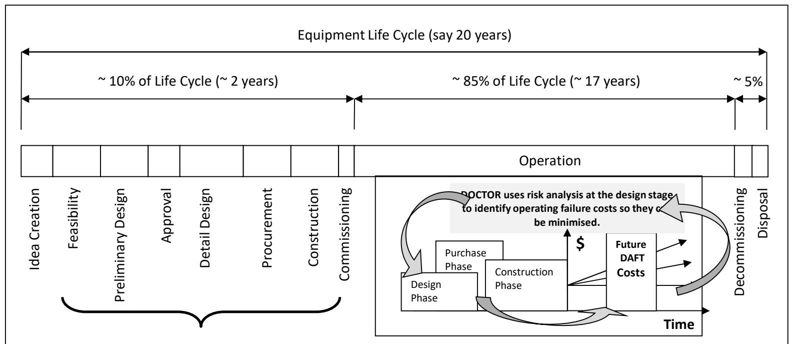
Maximising Life Cycle Profits and Minimising Operating and Maintenance Costs



The Project Phase is the time to control the future costs of the operation

All we can do during the operating phase is run and care for the equipment as it was designed to be. If the design requires expensive parts, and/or lots of downtime for maintenance and repairs, then the design is the problem, not the maintenance.

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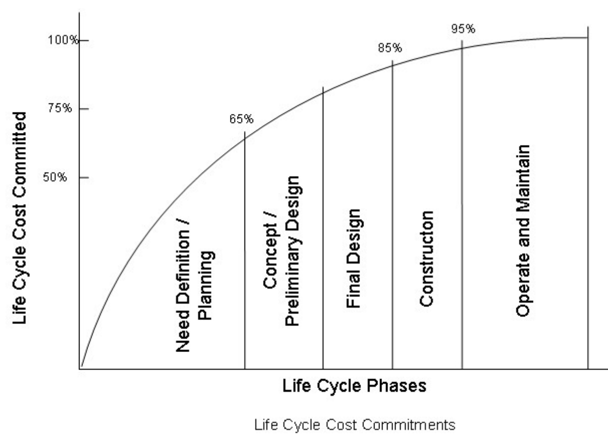
When Operating Costs are Committed



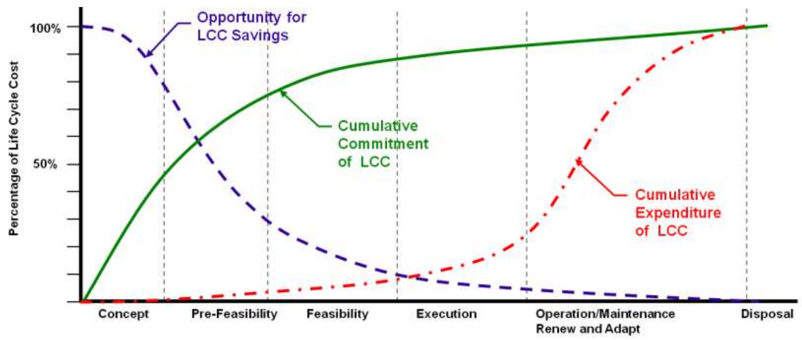
Life Cycle Cost Commitments

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

Once a plant is designed and built there is very little that can be done to reduce operating costs because they are substantially fixed by the plant's design. If you want low operating costs, this chart makes it clear that they are designed into the plant and equipment during feasibility, design and construction.

75

Cost Behaviour during the Life Cycle



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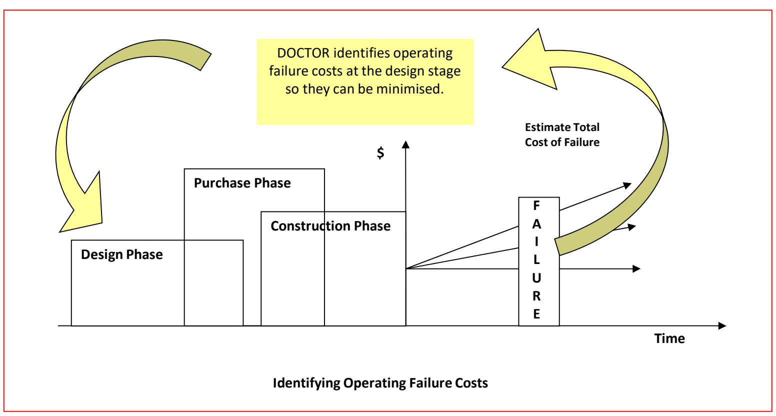
Design and Operation Costs Total Optimisation Review (DOCTOR)



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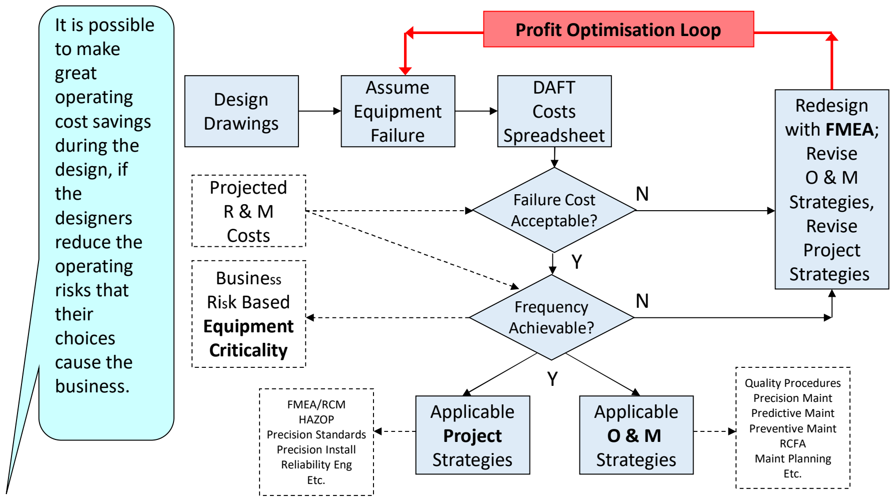
Life Cycle Risk Management Strategy

Optimised Operating Profit Method



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Physics of Failure

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Basic Failure Mechanism

Physics of failures deals with failure at atomic or molecular levels.

Physics of failure applied at the component Level at Equipment.

Some Example of failures.

Wear is the damaging, gradual removal or deformation of material at solid surfaces. Causes of wear can be mechanical (e.g., erosion) or chemical (e.g., corrosion). The study of wear and related processes is referred to as tribology.

Breakage due to overload; What load applied more then the capacity of machine element, Machine element fails In tensile, compressive or Shear forces on in combination of these forces.

Breakage due to fatigue failures :Fatigue is a failure mechanism that involves the cracking of materials and structural components due to cyclic (or fluctuating) stress. While applied stresses may be tensile, compressive or torsional, crack initiation and propagation are due to the tensile component.

Distortion: Due to excessive Load or heat component twist or these is change In shape and geometry of machine component.

Creep: Elongation of component (turbines) when working in Normal Load and high temperature.

Erosion : It is a degradation of material surface due to mechanical action, often by impinging liquid, abrasion by a slurry, particles suspended in fast flowing liquid or gas, bubbles or droplets, cavitation

80

Basic Failure Mechanisms

Corrosion : **Corrosion** is the irreversible damage or destruction of living tissue or material due to a chemical or electrochemical reaction. **Example**: A prime **example** of **corrosion** is rusting of iron or steel.

Oil Degradation: Oxidation is the reaction of materials with oxygen. It can be responsible for viscosity increase, varnish formation, sludge and sediment formation, additive depletion, Base oil breakdown, Filter plugging, loss in foam properties, acid number increase, rust and corrosion.

Electrical Motor Insulation failure :The main causes of insulation failure are dielectric contamination, temperature cycling, excessive overloads, excessive voltage stress due to overvoltage, and aging

Electronics Component failures. Failures can be caused by excess temperature, excess current or voltage, Environment contaminations mechanical shock, stress or impact

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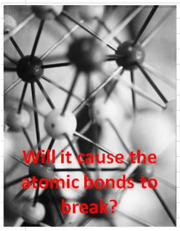
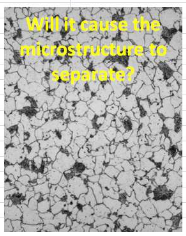
Factors that cause Atomic or Microstructure Failure	Component Manufacturing Events	Component Operational Stress Events (Horizontal, Vertical, Axial)	Component Environmental Events / Conditions	Component Life Cycle Situations
Compressive force overload	Metallurgy error	Pressure	Electrical discharge	Conception
Tensile force overload	Formulation error	Under-loaded	Thermal high	Feasibility
Shear force overload	Process conditions error	Interference fit tight	Thermal low	Approval
Cyclic stress fatigue	Chemical composition error	Interference fit loose	Corrosion	Final Design
Shock force overload	Interference fit tight	Insufficient load (looseness)	Erosion	Project Management
Punch hole in molecular structure	Interference fit loose	Physical deformation (bend, twist, squash)	Electrostatic	Installation
Melt molecular structure	Misalignment	Pressure hammer	Density gradient	Manufacture
Crack in molecular structure (dislocation)	Foreign inclusion	Shrinkage	Thermal gradient	Assembly
Material missing from molecular structure	Thin cross section	Expansion	Radiation	Operation
Material ripped from molecular structure		Misalignment	Electromagnetic	Maintenance
Wrong atoms in molecular structure		Unbalance	Diffusion	Overhaul / rebuild
Electromagnetic radiation		Punch (Impact load on small area)	Humidity	Transport
Chemical reaction		Hydraulic shock	Contaminant ingress	Storage
Crystal lattice attack		Vibration shock	Moisture ingress	Restitution
Depolymerisation		Abrasion (wear material away)	Product ingress	
		Hammer impact	Chemical reaction	
		Gouge	Vibration	
		Impingement (jet of fluid)	Rate of change of event	
		Foreign inclusion	Lubrication degradation	
		Detach-debond-delaminate	Oxidisation	
		Acts-of-God/Acts-of-Nature	Dissimilar materials	
		Fracture	Hygro-mechanical (moisture absorption)	
		Buckling	Inclusions	
		Yield	Crystal lattice attack	
		Creep	Elasticity degradation	
		Material fatigue	Metal migration	
		Physical abuse	Corrosion (pitting, galvanic, crevice, etc)	
		Vehicle impact	Threshold Voltage Shift	
			Leakage current	
			Power dissipation	
			Stray electrical current	
			Ionisation	





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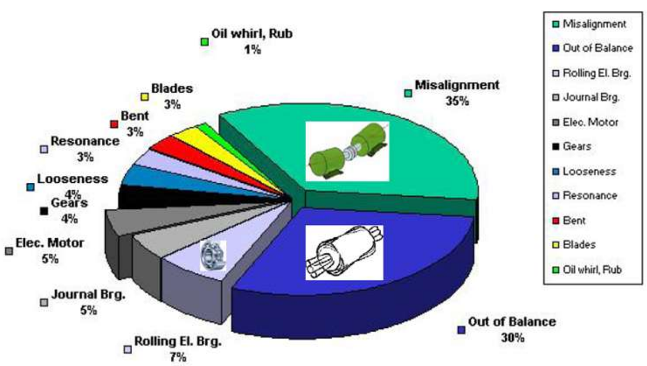
Here is what we Know about the Causes of Rotating Equipment Failure



Causes	Life Cycle Stage	Failure Mechanism	Physical failures
Misalignment	Commissioning	Excessive Cyclic stresses	Bearing failure in Fatigue
Out of Balance	Manufacturing	Excessive Cyclic stresses	Bearing failure in Fatigue
Rolling Bearing	Manufacturing/ Maintenance	Poor fitment Poor lubrication	Overload Fatigue failures
Electrical Motor	Manufacturing/ Maintenance	Over load Over voltages Poor cooling Poor Manufacturing/Wrong Duty Cycle	Coil Insulation failures

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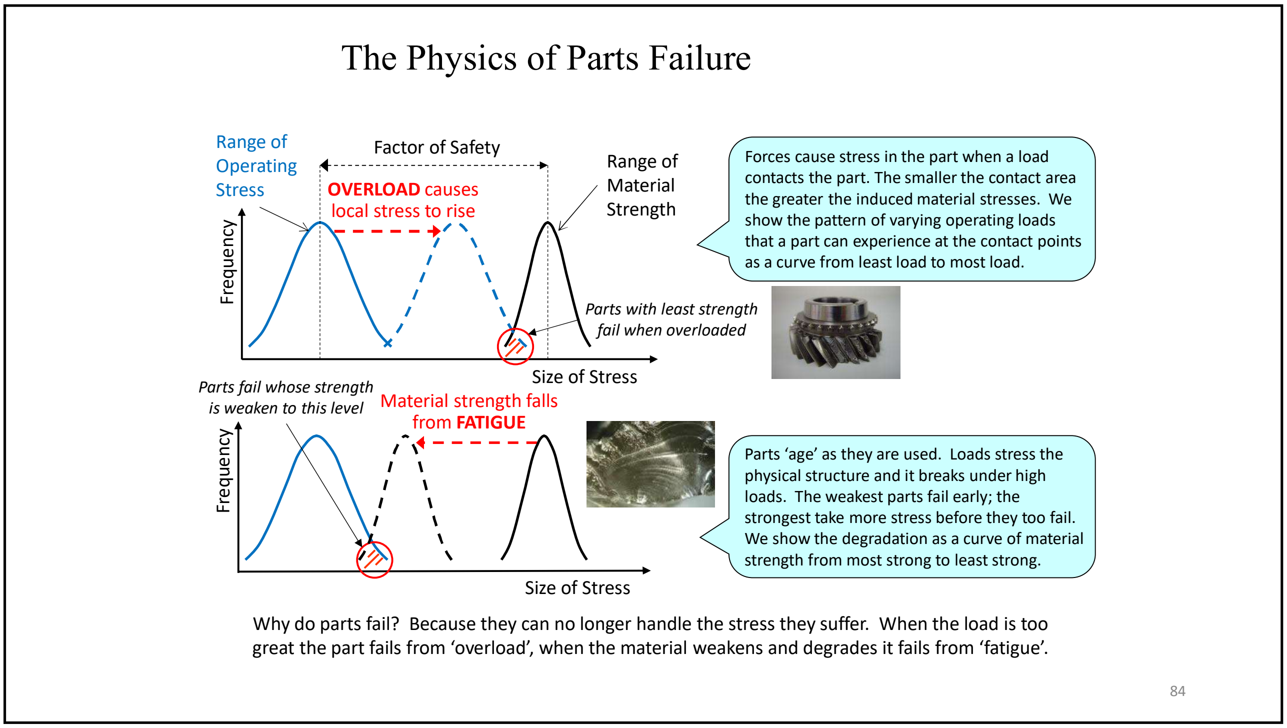
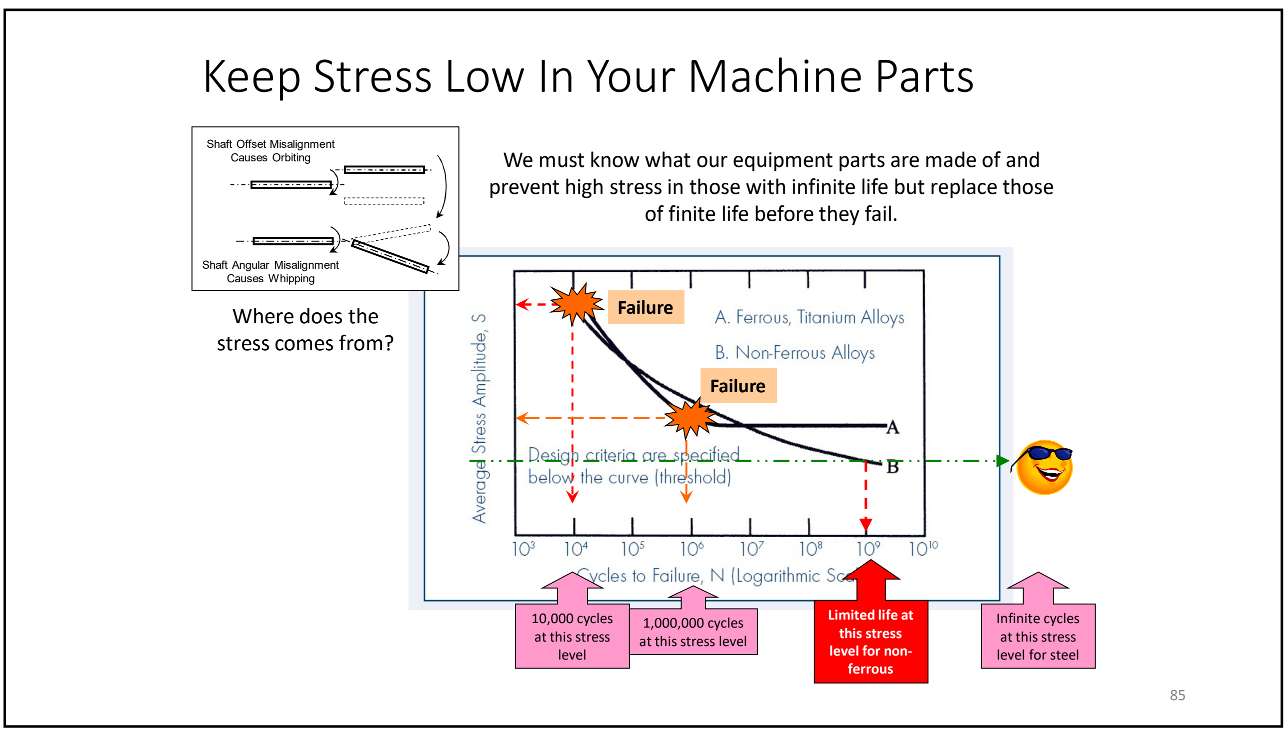
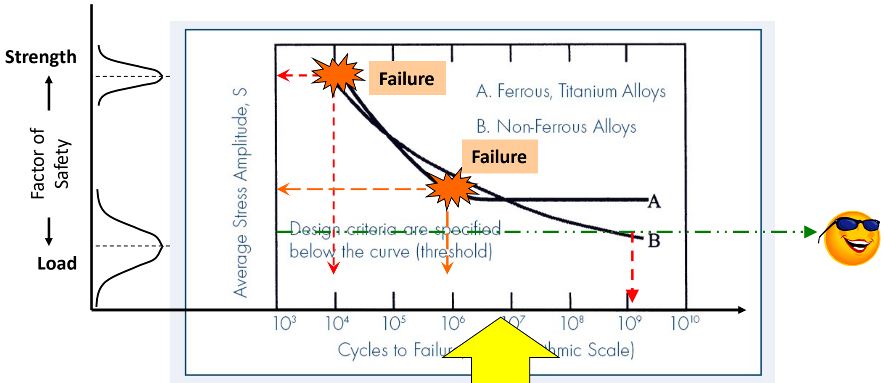

The Physics of Parts Failure
Range of Operating Stress
Factor of Safety
OVERLOAD causes local stress to rise
Range of Material Strength
Frequency
Parts with least strength fail when overloaded
Size of Stress
Forces cause stress in the part when a load contacts the part. The smaller the contact area the greater the induced material stresses. We show the pattern of varying operating loads that a part can experience at the contact points as a curve from least load to most load.
Parts fail whose strength is weaken to this level
Material strength falls from FATIGUE
Frequency
Size of Stress
Parts 'age' as they are used. Loads stress the physical structure and it breaks under high loads. The weakest parts fail early; the strongest take more stress before they too fail. We show the degradation as a curve of material strength from most strong to least strong.
Why do parts fail? Because they can no longer handle the stress they suffer. When the load is too great the part fails from 'overload', when the material weakens and degrades it fails from 'fatigue'.
84


Keep Stress Low In Your Machine Parts
Shaft Offset Misalignment Causes Orbiting
Shaft Angular Misalignment Causes Whipping
Where does the stress comes from?
We must know what our equipment parts are made of and prevent high stress in those with infinite life but replace those of finite life before they fail.
Failure
A. Ferrous, Titanium Alloys
B. Non-Ferrous Alloys
Failure
Design criteria are specified below the curve (threshold)
Average Stress Amplitude, S
A
B
10³ 10⁴ 10⁵ 10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰
10,000 cycles at this stress level
1,000,000 cycles at this stress level
Limited life at this stress level for non-ferrous
Infinite cycles at this stress level for steel
85

The Equipment Designer Wanted a Long, Trouble-Free Service Life

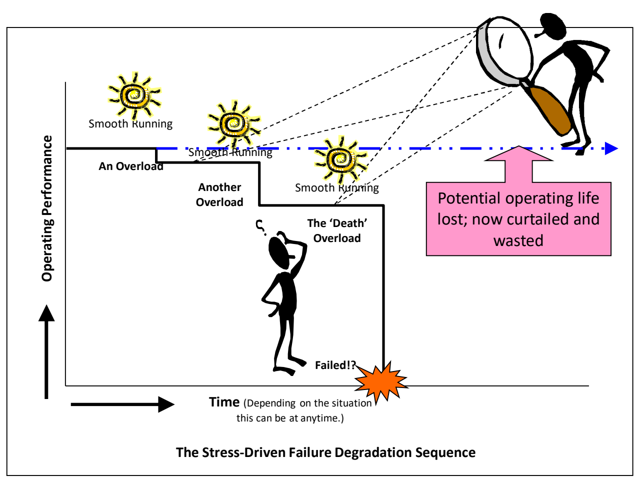


Using a Factor of Safety means the Designer intended for the operating stress to be so low that it produced a long, trouble-free service life

86

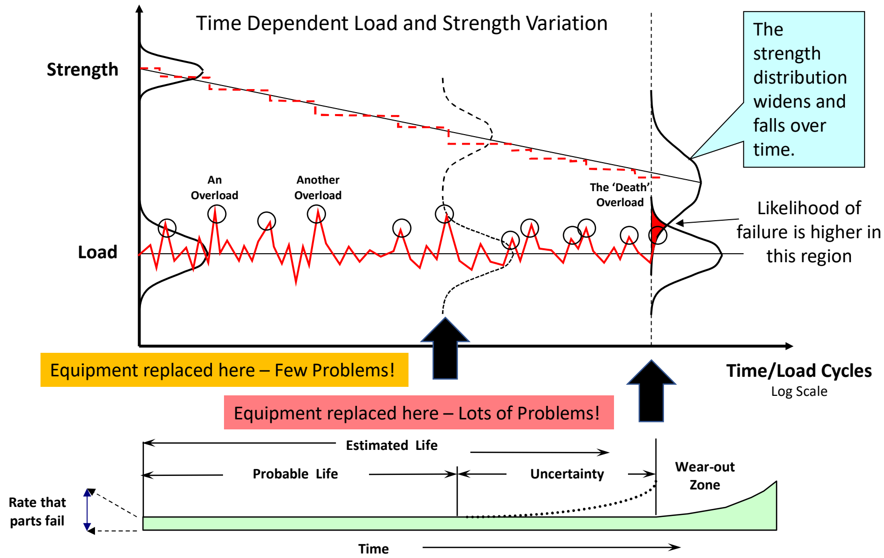
The Overload Cycle is Optional

Many parts fail without exhibiting warning signs of a coming failure – they show no evidence of degradation; there is just sudden catastrophic failure. In such cases the parts were too weak for the loads they had to take. In virtually every case those loads are imposed by human error.



87

Cause of Aging Failures



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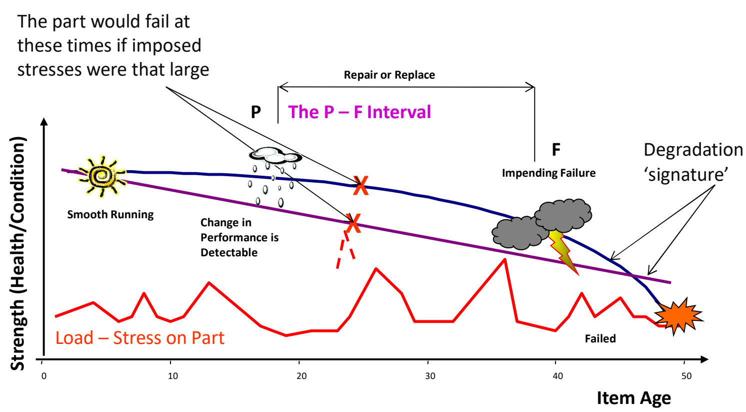
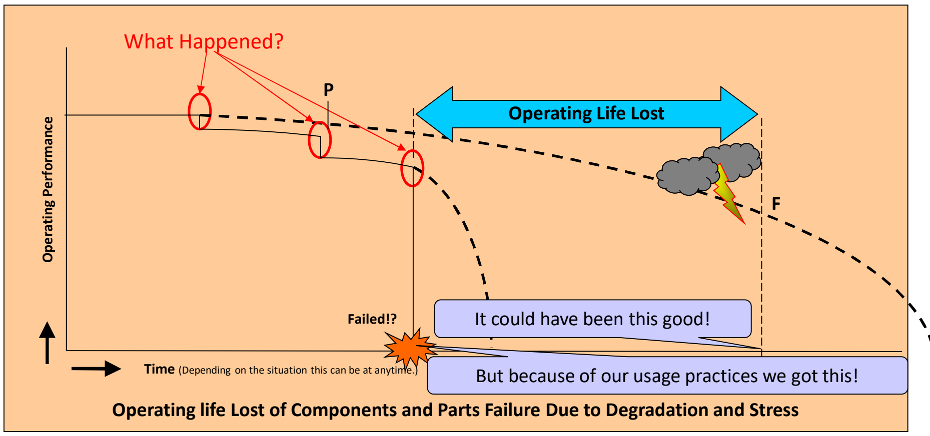
Equipment Degradation Cycle



We must condition monitor frequently enough to detect the onset of failure so we have time to address the failure before it happens.

89

Stress and Fatigue are Optional



We must prevent and control the circumstantial factors that cause both parts' fatigue <u>and</u> stress

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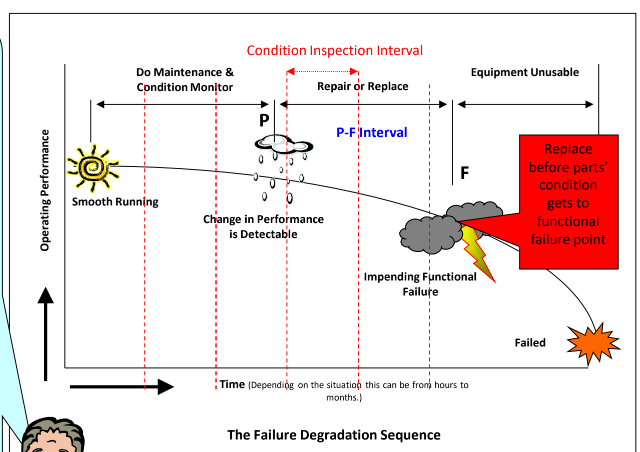
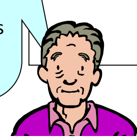
Degradation Cycle of Machines and Parts

Most parts show evidence, or exhibit warning signs, of failing. They follow a sequence of gradual degradation. As they degrade their condition changes. These changed conditions can be observed and the parts replaced before they fail. Some items, like electronic parts, can fail without warning. Situations of huge, sudden stress or overload can cause parts to immediately fail.





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Degradation Rate Vs Temperature

Svante Arrhenius
The Nobel Prize in Chemistry 1903

Degradation rate doubles for every 8 to 5 °C above Rated Operating Temperature

Possibly designers De-rated motor to allow for additional thermal insulation and higher operating temperature

Possibly everything is well sealed and abrasive material will cause no problems

"Yeah – Right!"

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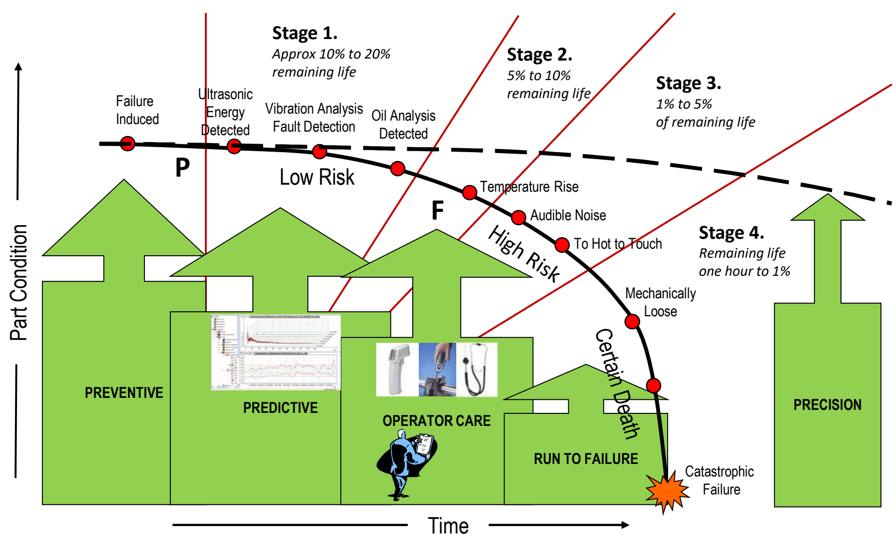
Roller Bearing Defect Severity



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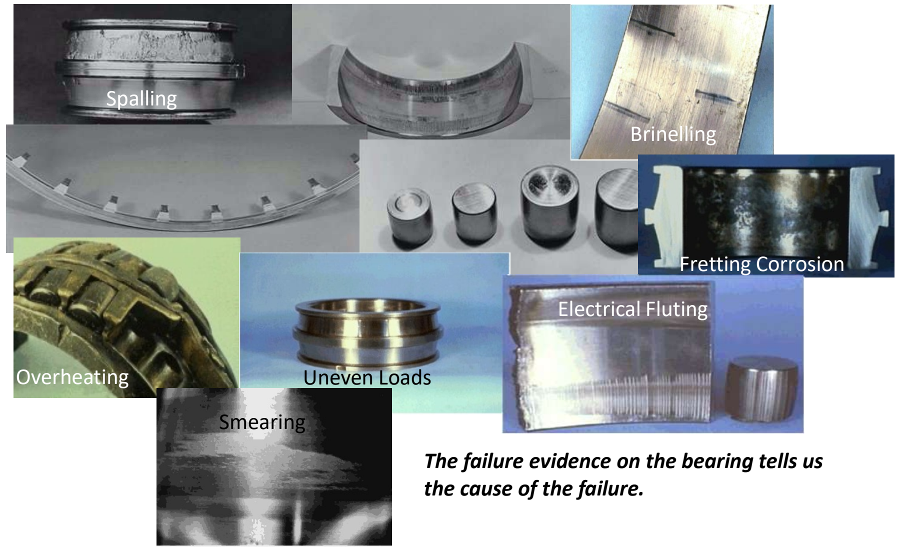
What Caused these Bearings to Fail?



The failure evidence on the bearing tells us the cause of the failure.

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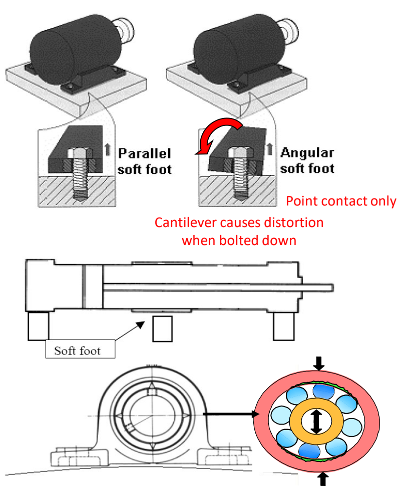
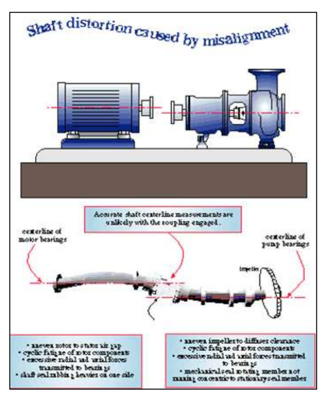
Stress from Distortion Fails Machinery



Far too common examples of soft-foot problems!



Shaft misalignment distorts and bends shafts which in turn overloads the shaft bearings

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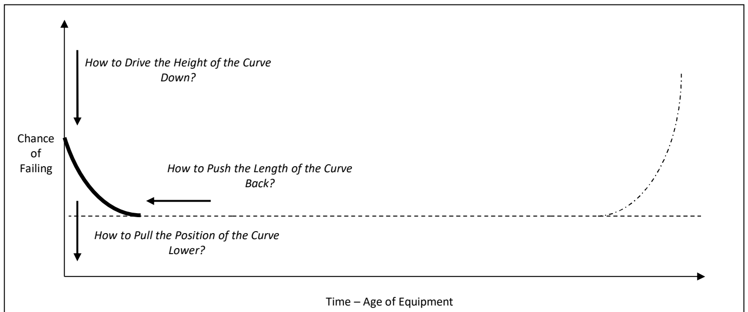
Failure Patterns – 'Infant Mortality'



Strategies for the Infant Mortality Maintenance Zone

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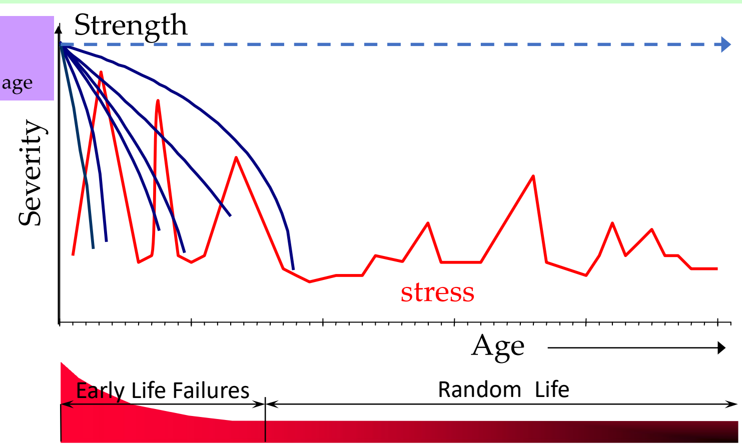
Infant Mortality and Poor Installation

If excessive loading starts from day 1 due to poor installation it fatigues material-of-construction (e.g. misalignment) Infant Mortality will occur

i.e. Failures clustered at very young age



Reliability Theory

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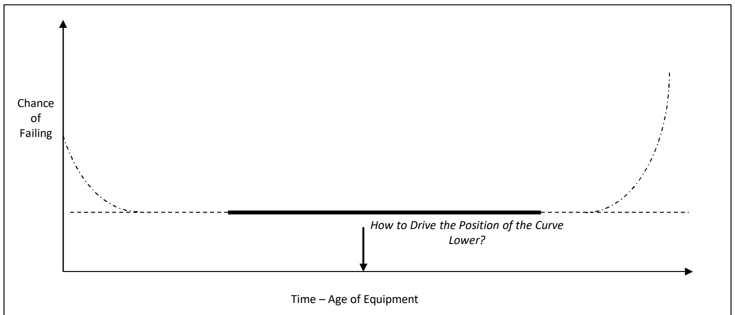
Failure Patterns – 'Random Failure'

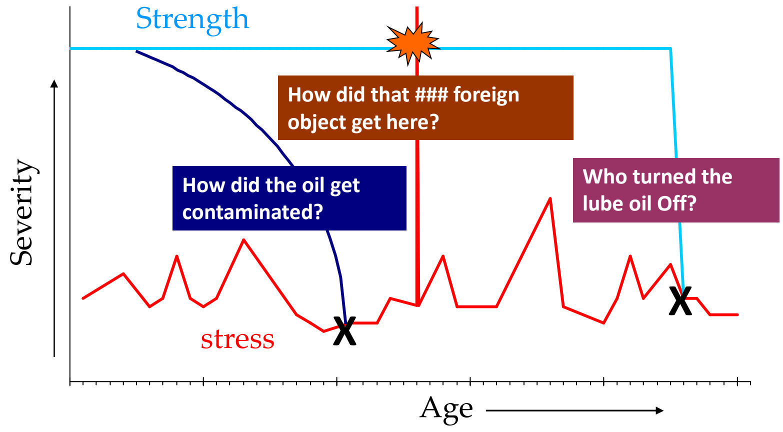


Strategies for the Random Failure Maintenance Zone

Because failure is probabilistic for 75%- 90% of parts, i.e. their failure is a chance event, this makes replacement of those parts on a certain date totally pointless. If the part did not show evidence of failure then it could have remained in operation for a very long time. You could spend money unnecessarily replacing a part that had nothing wrong with it.

99

Random Failure – Induced Stress



Thanks to Howard Witt Reliability Consulting for the slide

Reliability Theory

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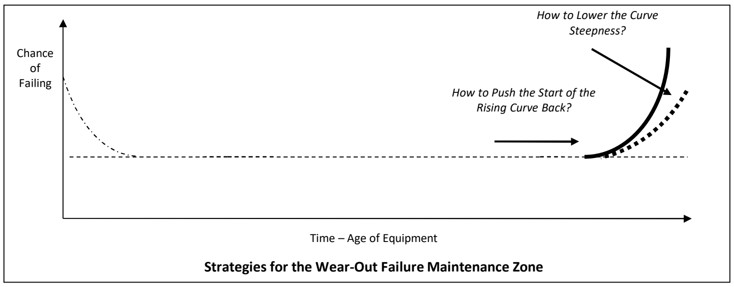
Failure Patterns – 'End-of-Life'



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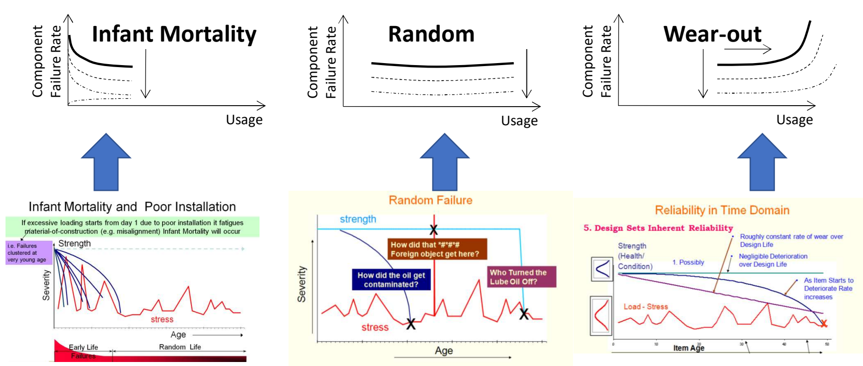
Strategy to Control Equipment Failures Curves



Understanding of events in terms of failure mechanisms and how they change item strength and/or stress applied Key to Good Strategies.

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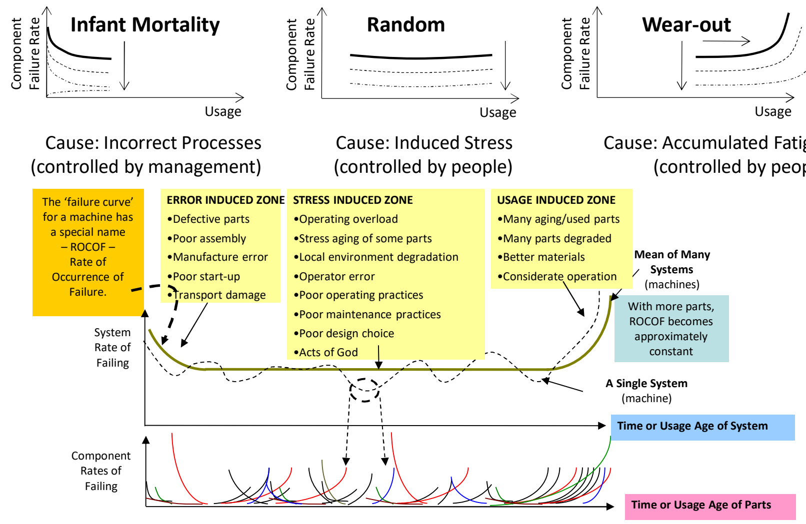
Cause and Effect of Our Equipment Failures



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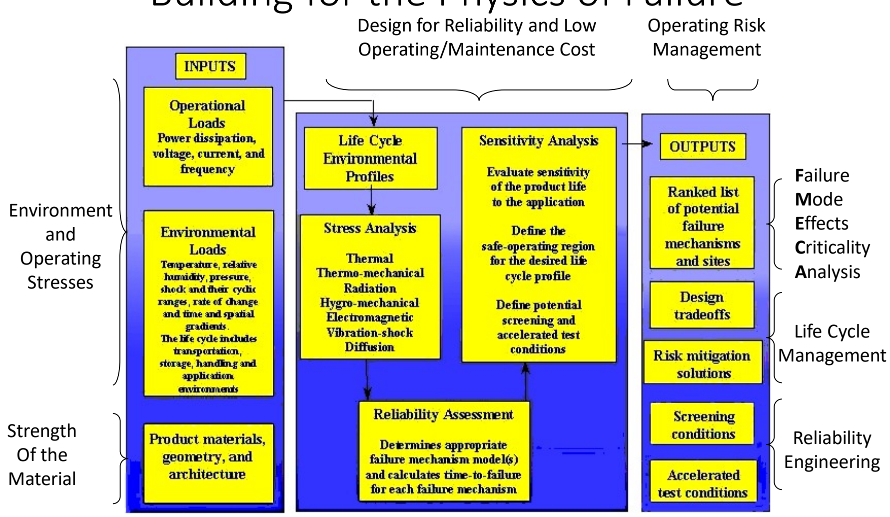
Building for the Physics of Failure



Source: Pecht, Michael., 'Why the traditional reliability prediction models do not work ..is there an alternative?', CALCE Electronic Product and Systems Centre of the University of Maryland, College Park, MD, 20742, USA.

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Failure Modes – "What You See/Hear when it Fails"

Example of an expanded list of failure modes							
1	Cracked/fractures	11	Fails to stop	21	Binding/jamming	31	Burned
2	Distorted	12	Fails to start	22	Loose	32	Collapsed
3	Undersize	13	Corroded	23	Incorrect adjustment	33	Overloaded
4	Oversize	14	Contaminated	24	Seized	34	Omitted
5	Fails to open	15	Intermittent operation	25	Worn	35	Incorrect assembly
6	Fails to close	16	Open circuit	26	Sticking	36	Scored
7	Fails open	17	Short circuit	27	Overheated	37	Noisy
8	Fails Closed	18	Out of tolerance (drifted)	28	False response	38	Arcing
9	Internal leakage	19	Fails to operate	29	Displaced	39	Unstable
10	External leakage	20	Operates prematurely	30	Delayed operation	40	Chafed

Source : Table 2 BS 5760-5. Superseded by **BS EN 60812**

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Human Error and its Management

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verses

"Machines and their parts are built to work within fine tolerances, and specific environments, and if not kept within those limits they will rapidly fail."

AND RIGHT HERE IS WHERE ALL THE TROUBLE STARTS … We do not fulfil our obligations to our machines

Machines Cannot Forgive Our Mistakes

It's not 'rocket science'. You just need to understanding that a machine requires we humans to build it so the internal tolerances are accurate, set it up accurately so it's not distorted, and make sure it always runs within those limits.

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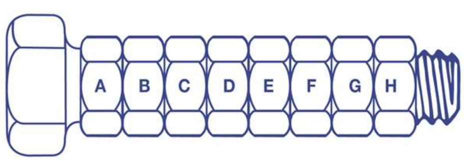
The Odds are Against Us Doing it Right!



Only one way to disassemble

40,000+ ways to incorrectly reassemble!

*Read the article "**The Human Factor**" in the workbook*

Source: Federal Aviation Authority, Human Error CD, 2008

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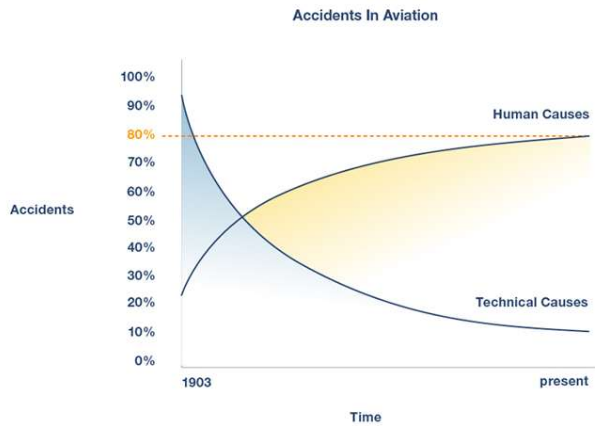
80% of Failure Events are Caused by Human Factors and Human Error



Nuclear Plants: 88 –72%
Barringer, H. Paul, 'Use Crow-AMSAA Reliability Growth Plots To Forecast Future System Failures'

Boiler Accidents: 82%
(USA, ASME Report 2002)

Dams: 90%
(Henry, P., 'Design Paradigms: Case Histories of Error and Judgment in Engineering')

Source: Federal Aviation Authority, Human Error CD, 2008

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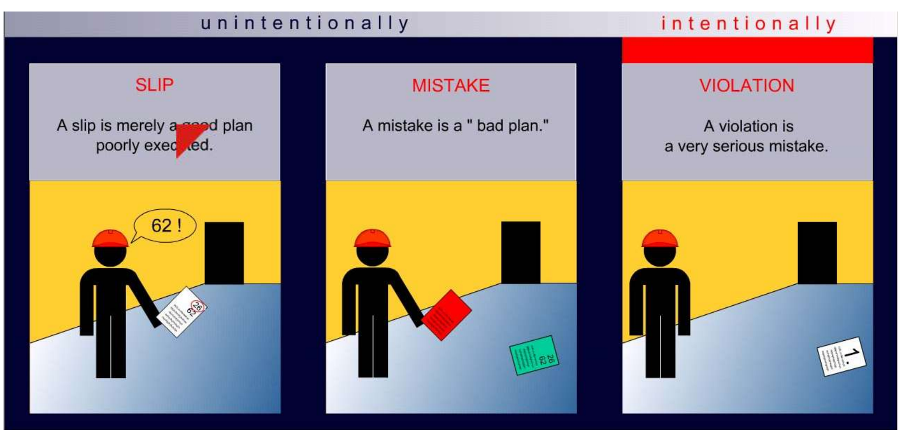
Types of Human Error



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Human Error

Following Classes:

Influenced By:

- Slips (lapse in attention): the intention is correct but the execution faulty

Mood, Stress, Health, Preoccupation

While thinking about a problem walk to where the workshop was 10 years ago

- Mistake: Faulty ideas on what should be done

Training, Procedures, Ability.

He thought it was the correct lubrication "How was I supposed to know that"

- Violations: Deliberate decision to ignore instructions.

Culture, Peer pressure Laziness, Overzealous

"Stuff that I just do it this way" / "I add a bit more just to be sure"

- Managerial Error: Poor policy, unwise decisions.

  Most errors can be traced back to this.

Culture, Ability, Knowledge, Experience, Laziness, Overzealous

"Knee Jerk Reaction" – "Policy on the Run" – "Risk Averse or Gung Ho"

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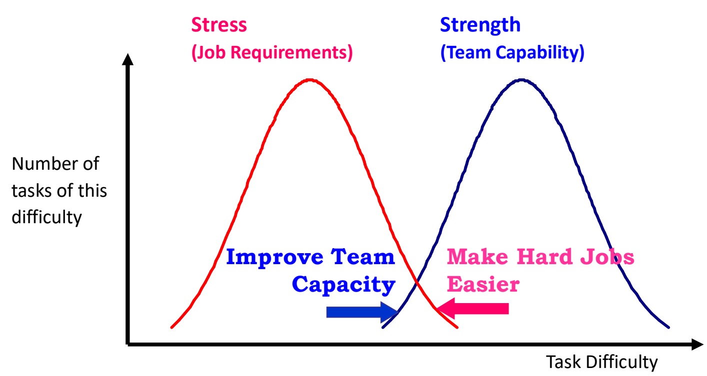
Task Difficulty Vs Team Capabilities



Human Error (how to reduce ….)?

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The Story in Human Error Rate Tables

	Read/ reason	Physical operation	Everyday yardstick
	Error rate (per task)		
Simplest possible task			
Fail to respond to annunciator	0.0001		
Overfill bath			0.00001
Fail to isolate supply (electrical work)		0.0001	
Read single alphanumeric wrongly	0.0002		
Read 5-letter word with good resolution wrongly	0.0003		
Select wrong switch (with mimic diagram)		0.0005	
Fail to notice major cross-roads			0.0005
Routine simple task			
Read a checklist or digital display wrongly	0.001		
Set switch (multiposition) wrongly		0.001	
Calibrate dial by potentiometer wrongly		0.002	
Check for wrong indicator in an array	0.003		
Wrongly carry out visual inspection for a defined criterion (e.g. leak)	0.003		
Fail to correctly replace PCB		0.004	
Select wrong switch among similar		0.005	

~5 sigma

~4.5 sigma

	Read/ reason	Physical operation	Everyday yardstick
	Error rate (per task)		
Read analogue indicator wrongly	0.005		
Read 10-digit number wrongly	0.006		
Leave light on			0.003
Routine task with care needed			
Mate a connector wrongly		0.01	
Fail to reset valve after some related task		0.01	
Record information or read graph wrongly	0.01		
Let milk boil over			0.01
Type or punch character wrongly		0.01	
Do simple arithmetic wrongly	0.01–0.03		
Wrong selection – vending machine			0.02
Wrongly replace a detailed part		0.02	
Do simple algebra wrongly	0.02		
Read 5-letter word with poor resolution wrongly	0.03		
Put 10 digits into calculator wrongly	0.05		
Dial 10 digits wrongly	0.06		
Complicated non-routine task			
Fail to notice adverse indicator when reaching for wrong switch or item	0.1		
Fail to recognize incorrect status in roving inspection	0.1		
New workshift – fail to check hardware, unless specified	0.1		
General (high stress)	0.25		
Fail to notice wrong position of valves	0.5		
Fail to act correctly after 1 min in emergency situation	0.9		

~4 sigma

~23 sigma

In failure rate terms the incident rate in a plant is likely to be in the range of 20×10^{-6} per h (general human error) to 1×10^{-6} per h (safety-related incident).

Source: Smith, David J., 'Reliability, Maintainability and Risk', Appendix 6, Seventh Edition, Elsevier – Butterworth Heinemann

The Table confirms that 'human element' error is real and unavoidable. We do not perform well when tasks are structured in ways that require great care and we perform especially badly under complicated, non-routine conditions. Add stress into that that mix and you get disaster.

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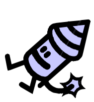
	Read/ reason	Physical operation	Everyday yardstick
	Error rate (per task)		
Read analogue indicator wrongly	0.005 .995		
Read 10-digit number wrongly	0.006 .994		
Leave light on			0.003 .997
Routine task with care needed			
Mate a connector wrongly		0.01 .99	
Fail to reset valve after some related task		0.01 .99	
Record information or read graph wrongly	0.01 .99		
Let milk boil over			0.01 .99
Type or punch character wrongly		0.01 .99	
Do simple arithmetic wrongly	0.01–0.03		
Wrong selection – vending machine	.99.97		0.02 .98
Wrongly replace a detailed part		0.02 .98	
Do simple algebra wrongly	0.02 .98		
Read 5-letter word with poor resolution wrongly	0.03 .97		
Put 10 digits into calculator wrongly	0.05 .95		
Dial 10 digits wrongly	0.06 .94		
Complicated non-routine task			
Fail to notice adverse indicator when reaching for wrong switch or item	0.1 .90		
Fail to recognize incorrect status in roving inspection	0.1 .90		
New workshift – fail to check hardware, unless specified	0.1 .90		
General (high stress)	0.25 .75		
Fail to notice wrong position of valves	0.5 .50		
Fail to act correctly after 1 min in emergency situation	0.9 .10		

In failure rate terms the incident rate in a plant is likely to be in the range of 20×10^{-6} per h (general human error) to 1×10^{-6} per h (safety-related incident).

E.g. Read it as 2 errors in every 100 times, which is the same as saying correct 98 times per 100

Notice the errors rise as things get more non-routine. And when stress is added, the error rate rockets up



A 'human dependant' process is a business or operating process where people make a decision, or act in it, or act on it.

(From Smith, Dr David J., *'Reliability and Maintainability and Risk'*, Extracts from Appendix 6, 7th Edition, Elsevier, 2005)

115

Likelihood of Human Error

- Human Error is difficult to manage as people can do unexpected things – That is, the failure types are unpredictable
- The likelihood of error increases when
- The stress on the person is excessive ("stressed out") or inadequate (boredom);
- The amount of information to process becomes greater or less than desirable;
- Decisions are made in haste;
- Unusual situations exist people become entrapped by their habits (task capture);
- The mental picture of the system is poor or the system is ill-defined (poor training, ability/demand mismatch, poor feedback, or poor definition of roles and responsibilities);
- A task is considered unnecessary or it is thought that errors will be fixed by others.

116

Human Factors – the limitations of People

Physical
- Size
- Gender
- Age
- Strength
- The five senses

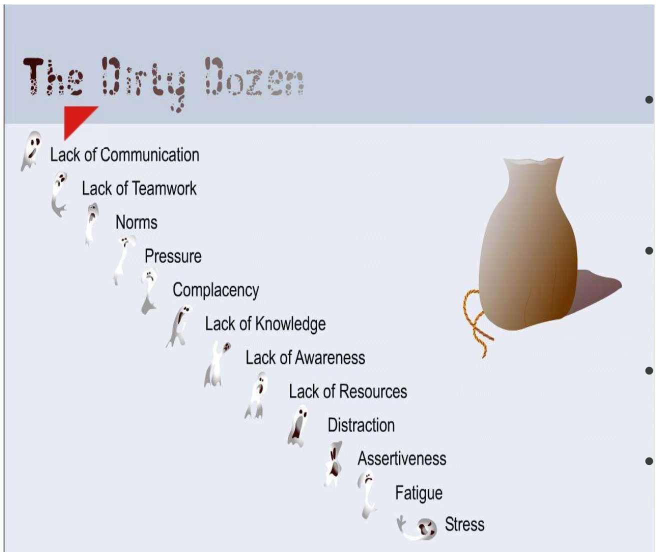
Psychological
- Experience
- Knowledge
- Training
- Attitude
- Emotional state

Physiological
- Health
- Nutrition
- Lifestyle
- Alertness/fatigue
- Chemical dependency

Psychosocial
- Interpersonal relations
- Ability to communicate
- Empathy
- Leadership

117

The 12 Most Common Causes for Human Errors

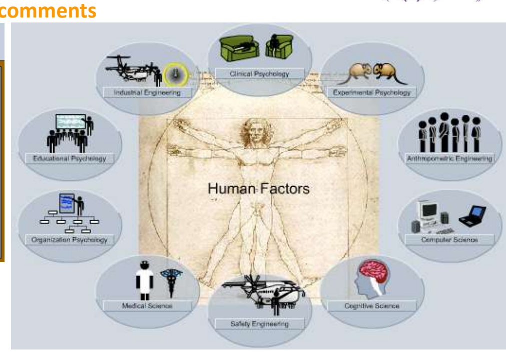


- Eliminate these causes and you have conquered most human errors
- Talk about your experience in any of these
- What are the causes in your company?
- What are the corrective actions?

118

Put on your "Human Factors Spectacles"

- **Sensitivity to human factors**
- **Knowledge of how human factors affect work and safety**
- **Objectively examine your world**
  - Look at others
  - Look at yourself
  - Look at the environment that surrounds you
- **Be willing to make suggestions and comments**



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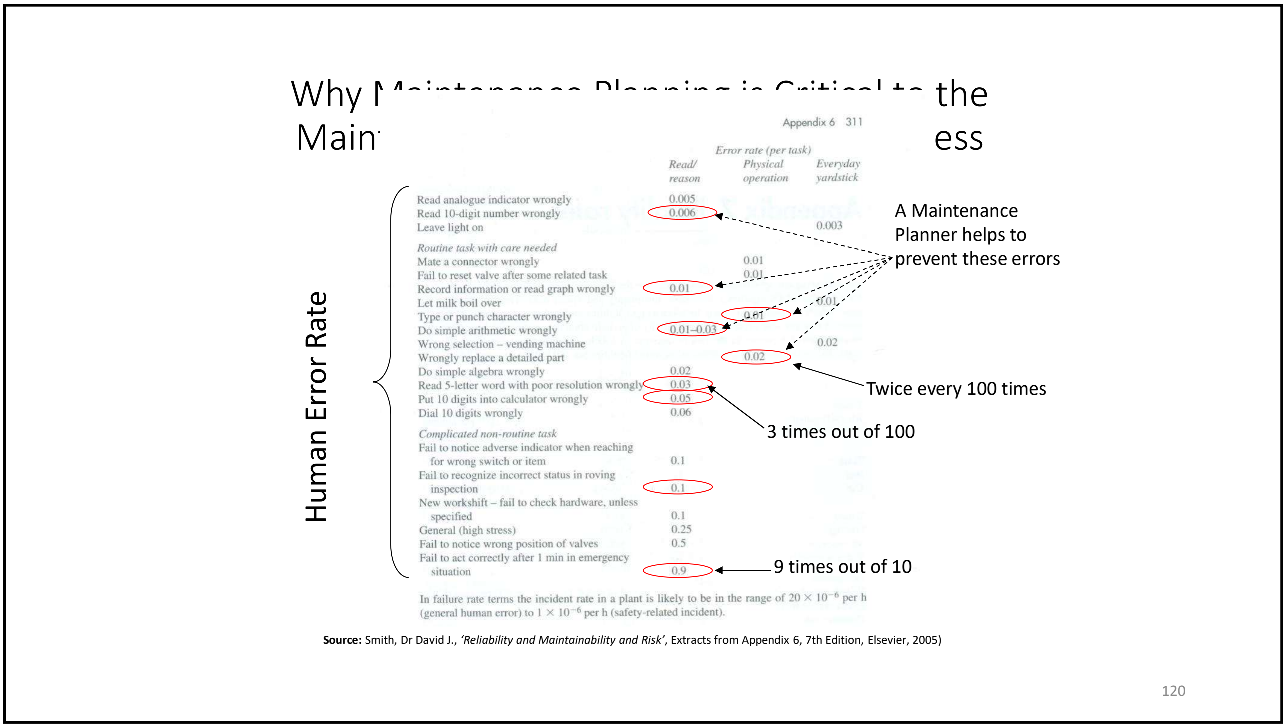
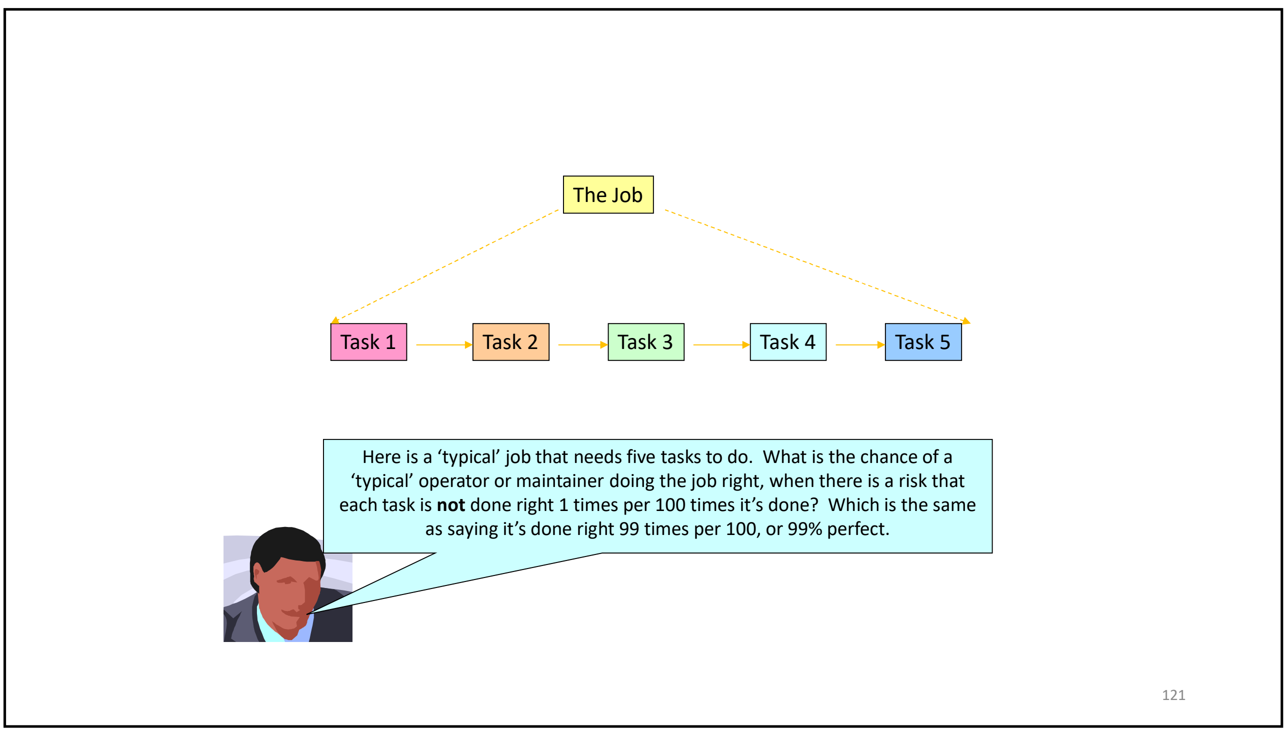
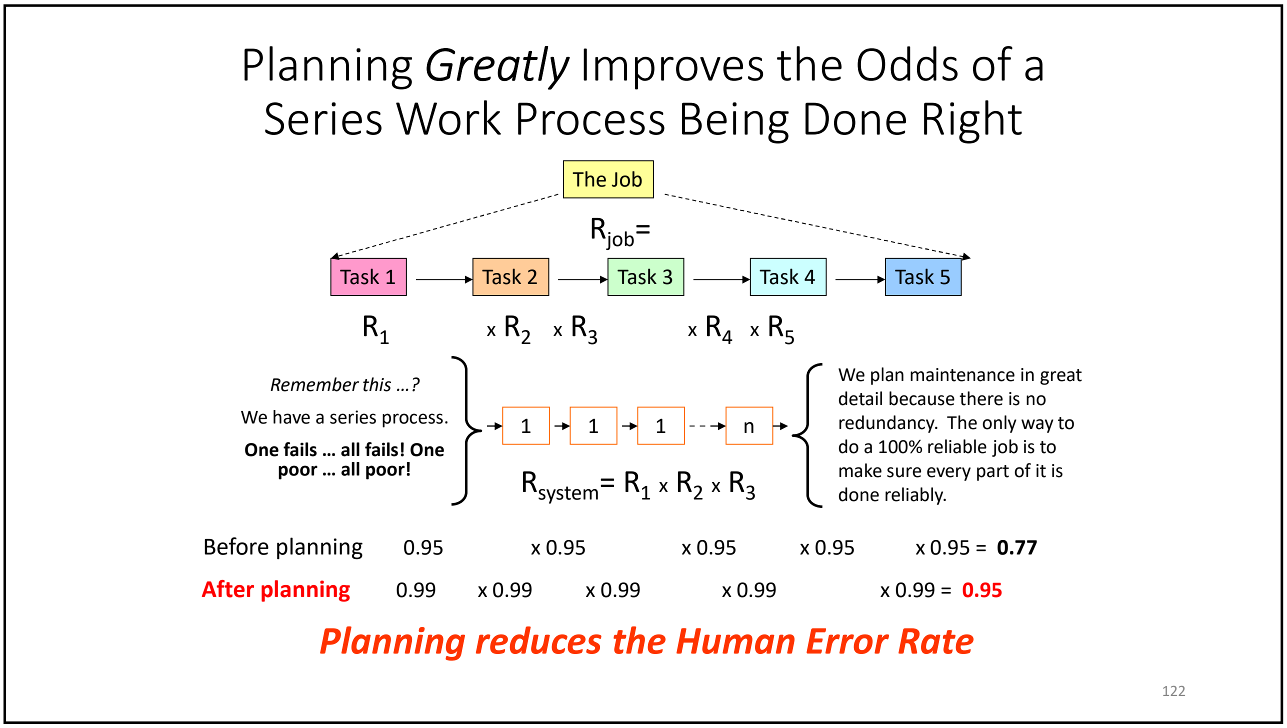


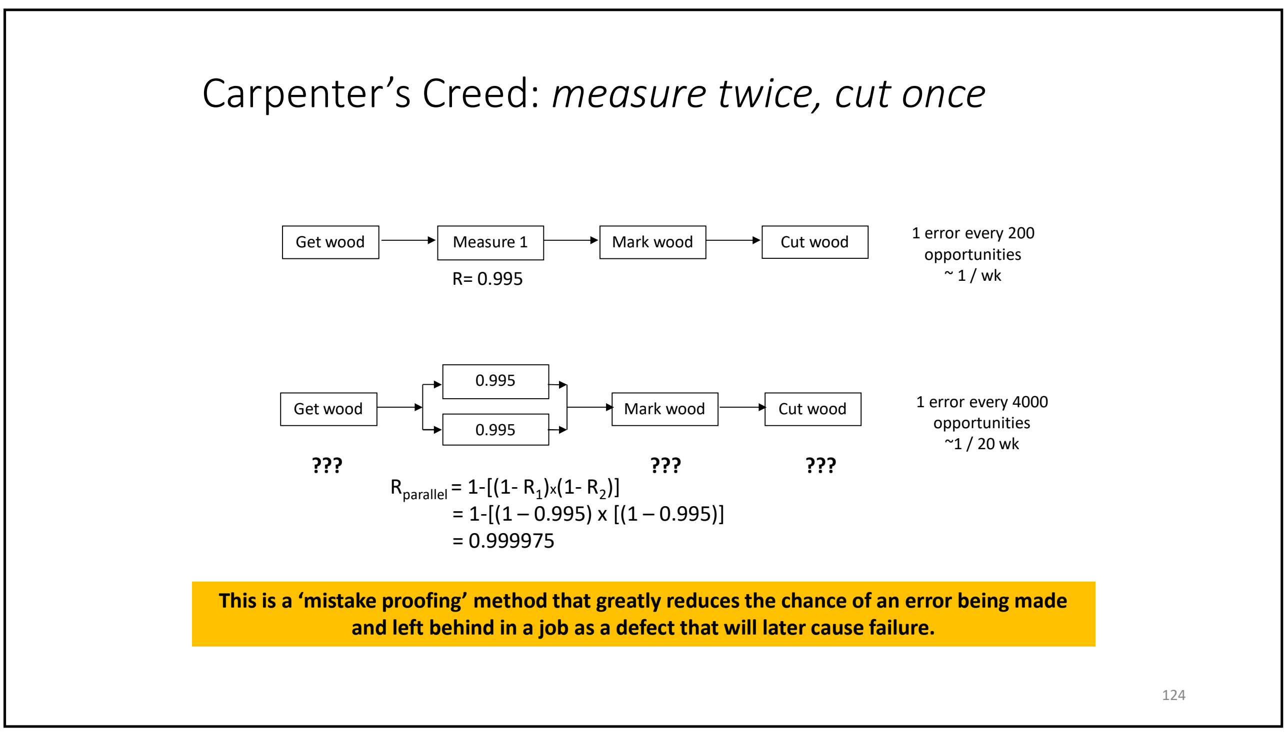
Appendix 6 311

	Error rate (per task) Read/ reason	Physical operation	Everyday yardstick
Read analogue indicator wrongly	0.005		
Read 10-digit number wrongly	0.006		
Leave light on			0.003
Routine task with care needed			
Mate a connector wrongly		0.01	
Fail to reset valve after some related task		0.01	
Record information or read graph wrongly	0.01		
Let milk boil over			0.01
Type or punch character wrongly		0.01	
Do simple arithmetic wrongly	0.01–0.03		
Wrong selection – vending machine			0.02
Wrongly replace a detailed part		0.02	
Do simple algebra wrongly	0.02		
Read 5-letter word with poor resolution wrongly	0.03		
Put 10 digits into calculator wrongly	0.05		
Dial 10 digits wrongly	0.06		
Complicated non-routine task			
Fail to notice adverse indicator when reaching for wrong switch or item	0.1		
Fail to recognize incorrect status in roving inspection	0.1		
New workshift – fail to check hardware, unless specified	0.1		
General (high stress)	0.25		
Fail to notice wrong position of valves	0.5		
Fail to act correctly after 1 min in emergency situation	0.9		

In failure rate terms the incident rate in a plant is likely to be in the range of 20×10^{-6} per h (general human error) to 1×10^{-6} per h (safety-related incident).




Planning *Greatly* Improves the Odds of a Series Work Process Being Done Right
The Job
R_{job}=
Task 1
Task 2
Task 3
Task 4
Task 5
R_1 x R_2 x R_3 x R_4 x R_5
Remember this ...?
We have a series process.
One fails ... all fails! One poor ... all poor!
1
1
1
n
R_{system}= R_1 x R_2 x R_3
We plan maintenance in great detail because there is no redundancy. The only way to do a 100% reliable job is to make sure every part of it is done reliably.
Before planning 0.95 x 0.95 x 0.95 x 0.95 x 0.95 = **0.77**
After planning 0.99 x 0.99 x 0.99 x 0.99 x 0.99 = **0.95**
Planning reduces the Human Error Rate
122


Carpenter's Creed: *measure twice, cut once*
Get wood
Measure 1
Mark wood
Cut wood
R= 0.995
1 error every 200 opportunities ~ 1 / wk
Get wood
0.995
0.995
Mark wood
Cut wood
1 error every 4000 opportunities ~1 / 20 wk
???
???
???
$R_{parallel}$ = 1-[(1- R_1)x(1- R_2)]
= 1-[(1 – 0.995) x [(1 – 0.995)]
= 0.999975
This is a 'mistake proofing' method that greatly reduces the chance of an error being made and left behind in a job as a defect that will later cause failure.
124

Quality Control and Assurance

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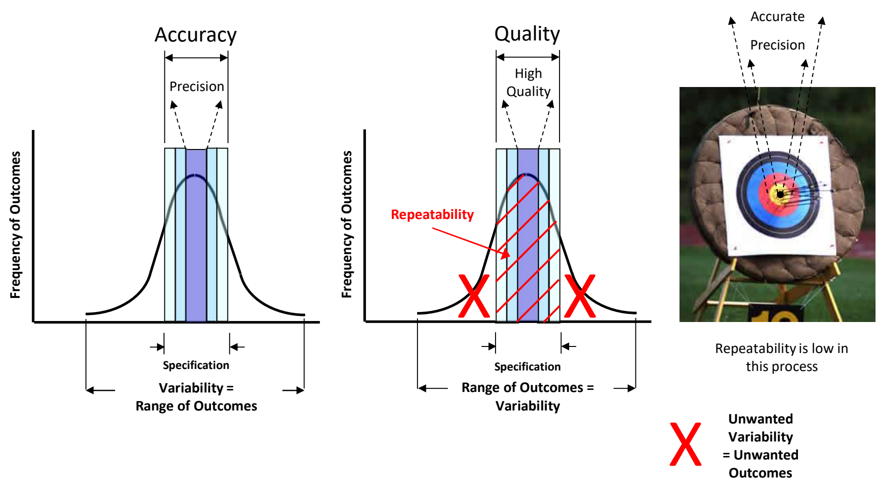
What do we mean by….

Quality, Precision, Repeatability, Variability



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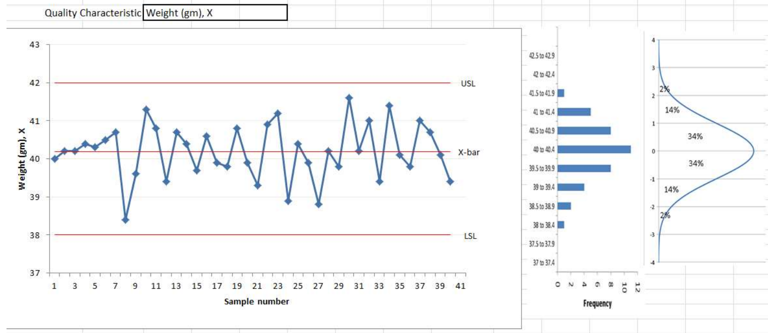
Graphically Tracking Behaviour of a Variable

Quality Characteristic Weight (gm), X



Statistics from data table		Process capability	
Process mean, X-bar	40.193	Upper specification limit, USL	42
Process standard deviation, S	0.721	Lower specification limit, LSL	38
X-bar + 3s	42.355	Cp	0.925
X-bar - 3s	38.030	CPU	0.836
		CPL	1.014
		Cpk	0.836
		Percent yield	99.27%

Thanks to Dick O'Brien from his process control lecture notes for the slide

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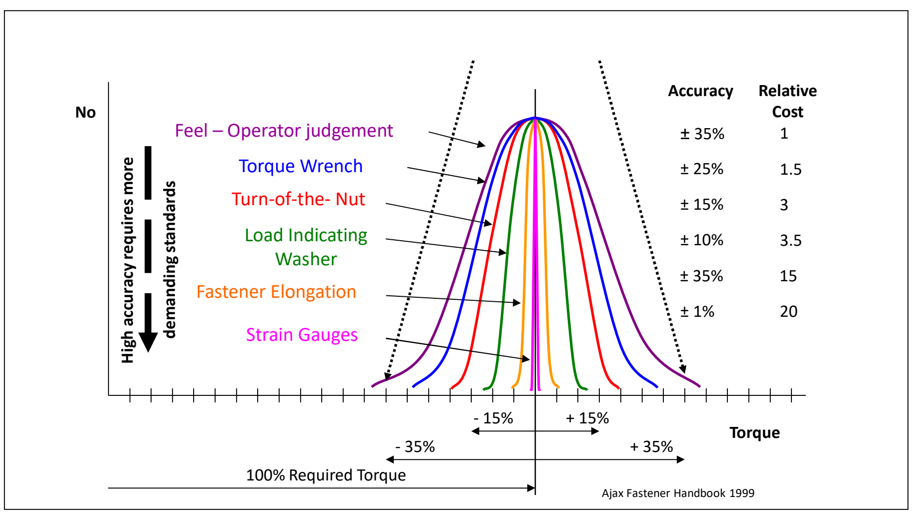
In doing up the same nut, two people can be 100% different in tension!

THAT CAN BE A DEADLY DANGEROUS VARIATION IN THE WRONG SITUATION.



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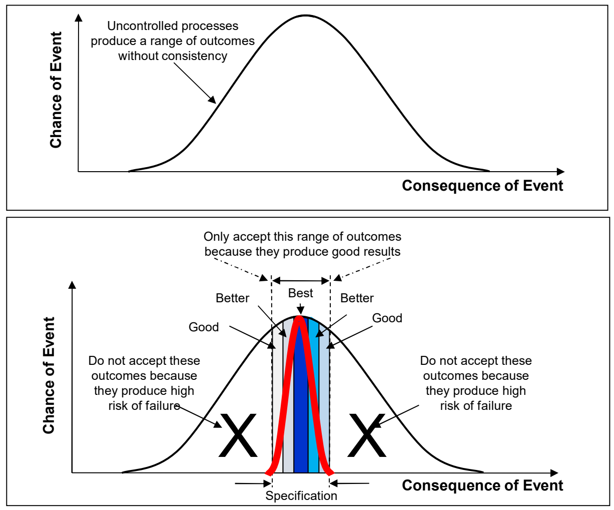
Controlling the Chance of a Failure Event



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Stop Defects and you Stop Problems

Defect elimination and failure prevention are where you have to focus if you want to stop problems. Otherwise the 'problem monkeys' that other people create, because they produced a defect and did not correct it, will all end-up sitting on your back to fix.

130

Equipment Maintenance System Quality Requirement

- **Standard Operating Procedures (SOPs):** Clear and well-documented standard operating procedures should be established for each maintenance task. These procedures outline the step-by-step process for performing maintenance, including safety precautions, tool requirements, and quality checkpoints.
- **Training and Qualifications**: Maintenance personnel should receive proper training and certification to ensure they have the necessary skills and knowledge to perform maintenance tasks accurately. Regular training updates should be provided to keep up with evolving equipment and technologies.
- **Inspection and Testing:** Regular inspections and testing should be conducted before, during, and after maintenance to identify potential defects, deviations from standards, and any issues that could lead to failures. This includes both functional testing and quality checks.
- **Quality Control Checkpoints:** Introduce quality control checkpoints at various stages of the maintenance process to verify that tasks are being carried out correctly and to identify any discrepancies early on.
- **Documentation:** Maintain comprehensive records of all maintenance activities, including the tasks performed, materials used, inspection results, and any deviations encountered. Accurate documentation provides an audit trail for future reference and analysis.
- **Precision Engineering Standards:** Align maintenance practices with precision engineering standards. This includes adhering to tolerance limits, material specifications, alignment requirements, and any other engineering guidelines relevant to the equipment.
- **Audits and Reviews:** Periodically conduct internal audits and reviews of the maintenance processes to ensure compliance with established procedures and standards. External audits can also provide valuable insights and validation.
- **CMMS:** Develop a comprehensive maintenance management software that incorporates SOPs, inspection checklists, documentation templates, and reporting tools.
- **Continuous Improvement:** Establish a feedback loop that encourages personnel to provide suggestions for process improvement based on their experiences. Regularly review and update maintenance procedures based on lessons learned and technological advancements.

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Equipment Maintenance Quality Requirement

- **Accuracy:** Maintenance tasks must be performed accurately to avoid introducing errors or causing further issues. This includes correctly identifying the problem, using the right tools and techniques, and following the manufacturer's guidelines.
- **Safety:** Safety should always be a top priority. Maintenance tasks should be performed in a way that minimizes risks to the technicians and the equipment itself. This includes using appropriate personal protective equipment, following safety protocols, and ensuring that the vehicle is properly secured during maintenance.
- **Reliability:** The goal of maintenance is to enhance the reliability of the Equipment. Quality measures should ensure that the maintenance work leads to improved performance, reduced breakdowns, and increased longevity of the car.
- **Quality Parts:** When replacing parts, using high-quality, genuine parts is essential. Substandard or counterfeit parts can lead to further problems and reduced reliability.
- **Proper Tools and Equipment:** Using the right tools for the job ensures that tasks are performed correctly and efficiently. It also minimizes the risk of damaging components during maintenance.
- **Testing and Validation**: After completing maintenance, thorough testing and validation should be performed to ensure that the vehicle is functioning properly. This might involve test drives, diagnostic tools, and performance checks.
- **Training and Qualifications:** Maintenance tasks should be carried out by trained and qualified technicians. Having certified professionals perform the work ensures that it's done to a high standard.
- **Clear Communication:** Effective communication between technicians, supervisors, and vehicle owners is vital. This includes discussing the work to be done, explaining the results, and providing recommendations for ongoing care.
- **Environmental Considerations:** Maintenance tasks should be performed in an environmentally responsible manner. This includes proper disposal of waste materials, such as used oil and old parts.
- **Documentation:** Proper documentation of maintenance tasks is crucial. This includes recording the work performed, parts replaced, adjustments made, and any other relevant details. Accurate documentation helps with tracking maintenance history and identifying patterns.

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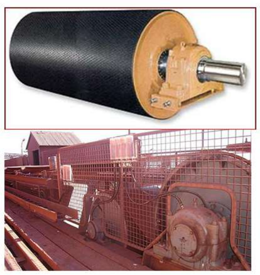
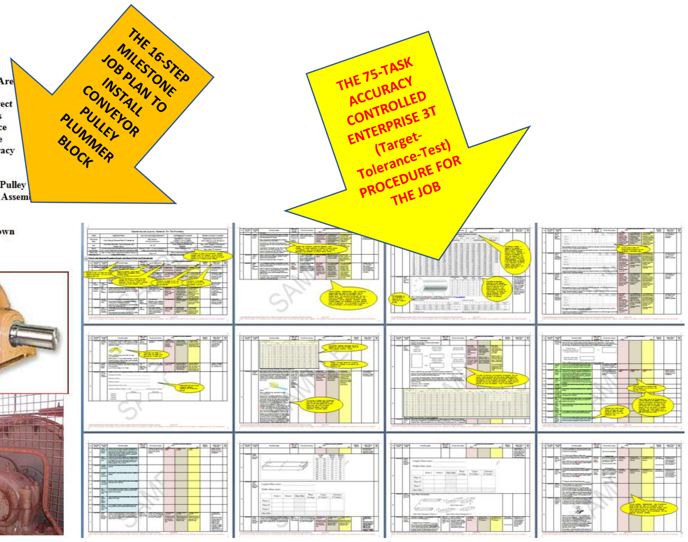
A Job Plan is Not a Job Procedure

1. Prepare for Job in Dirt-Free Work Are
2. Safe Isolation and Handover
3. Check Parts and Materials are Correct
4. Access Plummer Block and Bearings
5. Check Shaft Condition and Tolerance
6. Measure Bearing Internal Clearance
7. Measure Plummer Base Plate Accuracy
8. Locate Bearings on Shaft
9. Mount Bearings on Shaft
10. Position Plummer Blocks and Place Pulley
11. Complete Plummer Block and Seals Assem
12. Align Plummer Blocks
13. Lubricate Bearing and Seals
14. Locate Plummer Blocks and Bolt Down
15. Commission and Test
16. Clean-up and Hand Back





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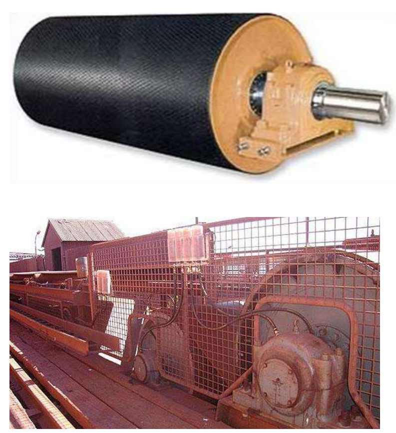
What is Wrong with this Job Plan?

JOB PLAN TO INSTALL NEW BEARINGS IN CONVEYOR PULLEY PLUMMER BLOCKS

1. Prepare for Job in Dirt-Free Work Area
2. Safe Isolation and Handover
3. Check Parts and Materials are Correct
4. Access Plummer Blocks and Bearings
5. Check Shaft Condition and Tolerance
6. Measure Bearing Internal Clearance
7. Measure Plummer Base Plate Accuracy
8. Locate Bearings on Shaft
9. Mount Bearings on Shaft
10. Position Plummer Blocks and Place Pulley
11. Complete Plummer Block and Seals Assembly
12. Align Plummer Blocks
13. Lubricate Bearing and Seals
14. Align Plummer Blocks and Bolt Down
15. Commission and Test
16. Clean-up and Hand Back



ANSWER: *no organisation, no times, no quality standards = no control of the job*

134

Develop a Job Plan with Quality Specifications that Indicate Achievement of Milestone Steps

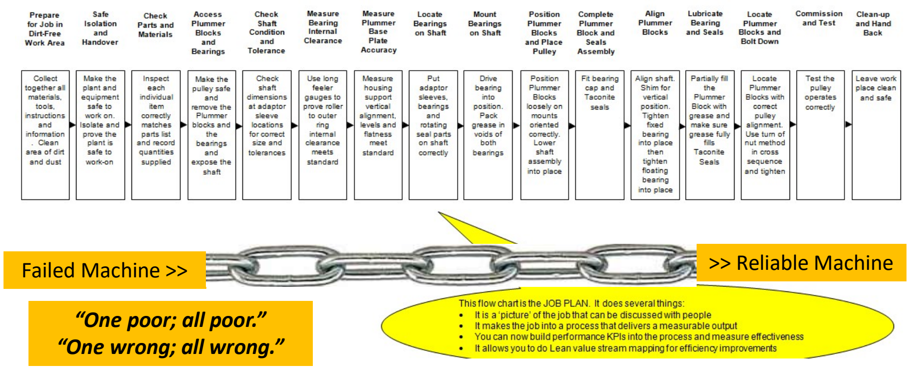
JOB PLAN TO INSTALL NEW BEARINGS IN CONVEYOR PULLEY PLUMMER BLOCKS

1. Work Area **prepared to site dirt-free work standard**
2. Safe Isolation and Handover **delivered from Operator**
3. Check Parts and Materials **are correct to BOM**
4. Plummer Blocks and Bearings **accessed for safe installation**
5. Shaft Condition and Tolerance **checked against OEM values**
6. Bearing Internal Clearance **measured against OEM values**
7. Plummer Base Plate **measured against OEM values**
8. Bearings on Shaft **located to OEM values**
9. Bearings on Shaft **mounted to OEM standards**
10. Plummer Blocks and Pulley **positioned to OEM standards**
11. Complete Plummer Block and Seals **assembled and positioned to OEM standards**
12. Plummer Blocks **aligned to OEM standards**
13. Bearing and Seals **lubricated to OEM standards**
14. Plummer Blocks **aligned and bolted to OEM standards**
15. Commission and Test that **operating specification is met**
16. Clean-up and Hand Back **to site workplace cleanliness standards**

135

Job Plan as a Process Flow Diagram makes Series Implications and Risks Clear

Job Plan of the Process for Installing Spherical Roller Bearings with Adaptor Sleeve in Plummer Blocks with Taconite Seals on a Conveyor Pulley Shaft



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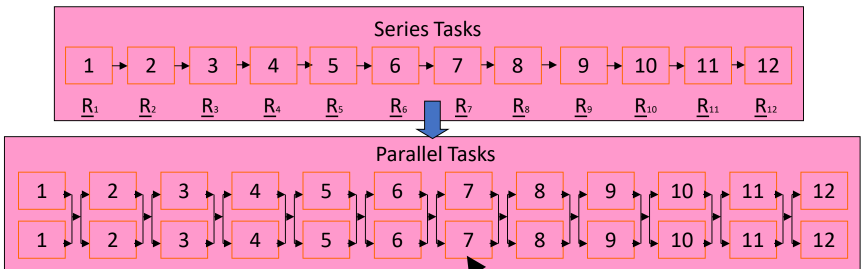
Improving Series Process Reliability

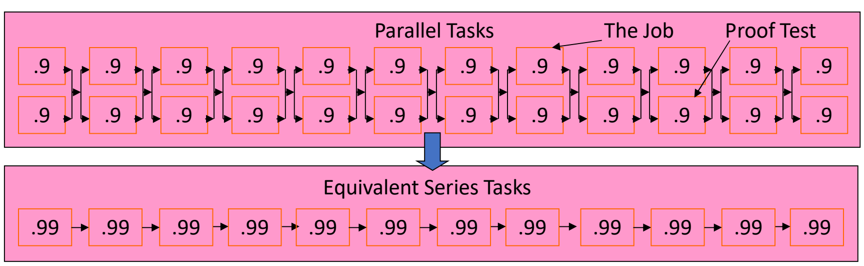
- *How to make each task more certain?*
- *How certain?*

- *Can we include redundancy and turn tasks into a parallel arrangement?*



Add a 'Proof Test' to each task

137



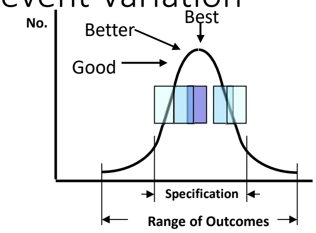
Adding a proof test requirement to each task *(even though the test is done right only 90% of the time)* **has made each task into a parallel task. That simple change** *(though still error prone)* **has lifted the chance of doing the job right-first-time from 28% to 89%!**

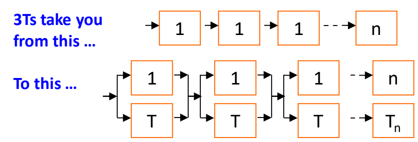
138

Accuracy Controlled SOPs Prevent Variation

- Specify the 3Ts (Target, Tolerance, Test) for precision and accuracy
- Range the tolerance 'good, better, best'
- Make 'best' the world-class performance
- Make the SOP into a table of successive tasks in a column
- Provide columns for 3Ts and ranges
- Give all tasks a 3T
- Advise what to do when out of tolerance
- Get a signature when 3T is done to tolerance

3T SOPs give feedforward control





You will stop defects and prevent variation if you use the 3Ts in your SOPs. The 'Test' in every task creates a parallel arrangement. And that will dramatically increase the likelihood of the whole task being done 100% right.

139

Including 3T Failure Prevention in SOPs

Task Step No.	Task Step Owner	Task Step Name	Tools & Condition	Full Description of Task	Test for Correctness	Tolerance Range			Record Actual Result	Action if Out of Tolerance	Sign-off After Complete
		(Max 3 – 4 words)		(Include all tables, diagrams and pictures here)		Good	Better	Best			

Test

Tolerance

Target

Tell people how to fix the problem

Typical Layout for 3T – Target, Tolerance, Test – Failure Prevention Procedure

When procedures are written with the 3Ts you can guide people right to the outcome they need to deliver. We build into 3T procedures the necessary actions that, when performed, will deliver the necessary task reliability. We give people a way to check that their work is exactly what it needs to be. They self-improve and gain the self-satisfaction of having done a great job.

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RCA and FMEA

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Root Cause Analysis Introduction

World-of- today is result of as-series of Causation.

Causation provides relations and linkages among various events.

Cause itself does not convert in to effect. The Cause will Interact with environment variables and produce effect (if a given environment is static Cause and Effect will one and same)

In absence of Exhaustive knowledge regarding some process or product leads to “Thread the path of causation series and search for Root Cause”

In series of Causation “Root cause” is most effective and Efficient point to act-upon to influence the outcomes .

142

Root Cause Analysis

- RCA is a useful process for understanding and solving a problem. RCA is a systematic process for identifying root cause of problems or events and an approach for responding them
- RCA defined as analytical tool that can be used to perform a comprehensive system based review of critical incidents
- RCA is Based on the basic idea that effective management requires more than merely putting-off-fires for problem that develop but finding a way to prevent them.
- RCA means finding the specific sources that created the problem so the effective actions can be taken to prevent recurrence of the situation.
- Identify barrier and causes of problems so the permanent solutions can be found
- Develop the logical approach to problem solving using data already exist with organization
- Establish repeatable , step by step processes in which one process confirms the results of the other

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RCA Application Across Spectrum of Product, Process and Service Industries

- Office Processes and Procedures
- Quality Control Problems
- Healthcare Incident Analysis
- Safety-based Situations or Accident Analysis
- Failure Analysis in Engineering and Maintenance
- Change Management or Continuous Improvement Activities
- Computer Systems or Software Analysis

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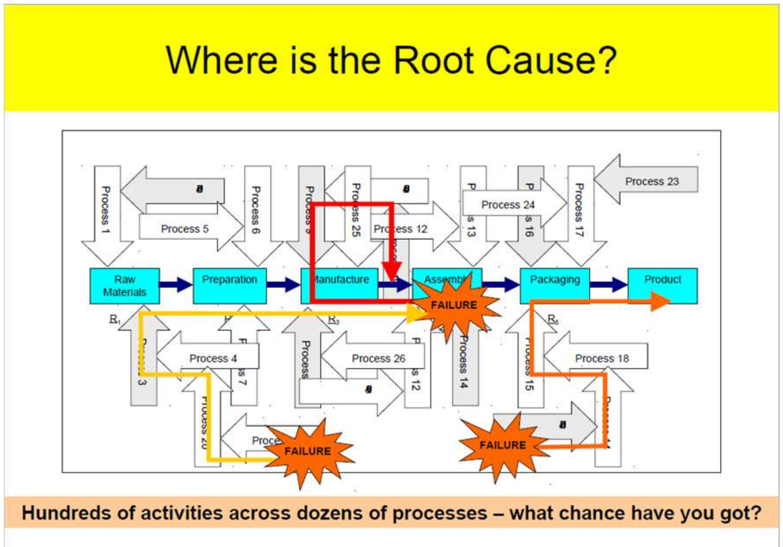
Root Cause Analysis



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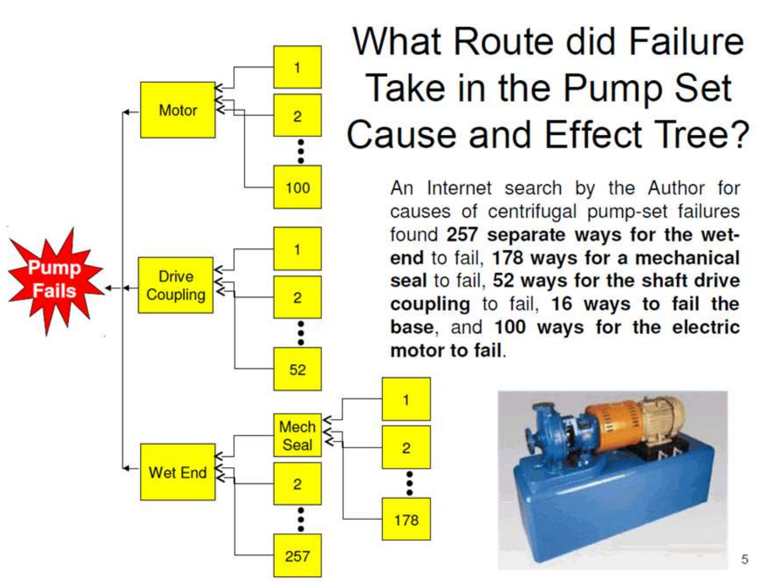
Root Cause Analysis



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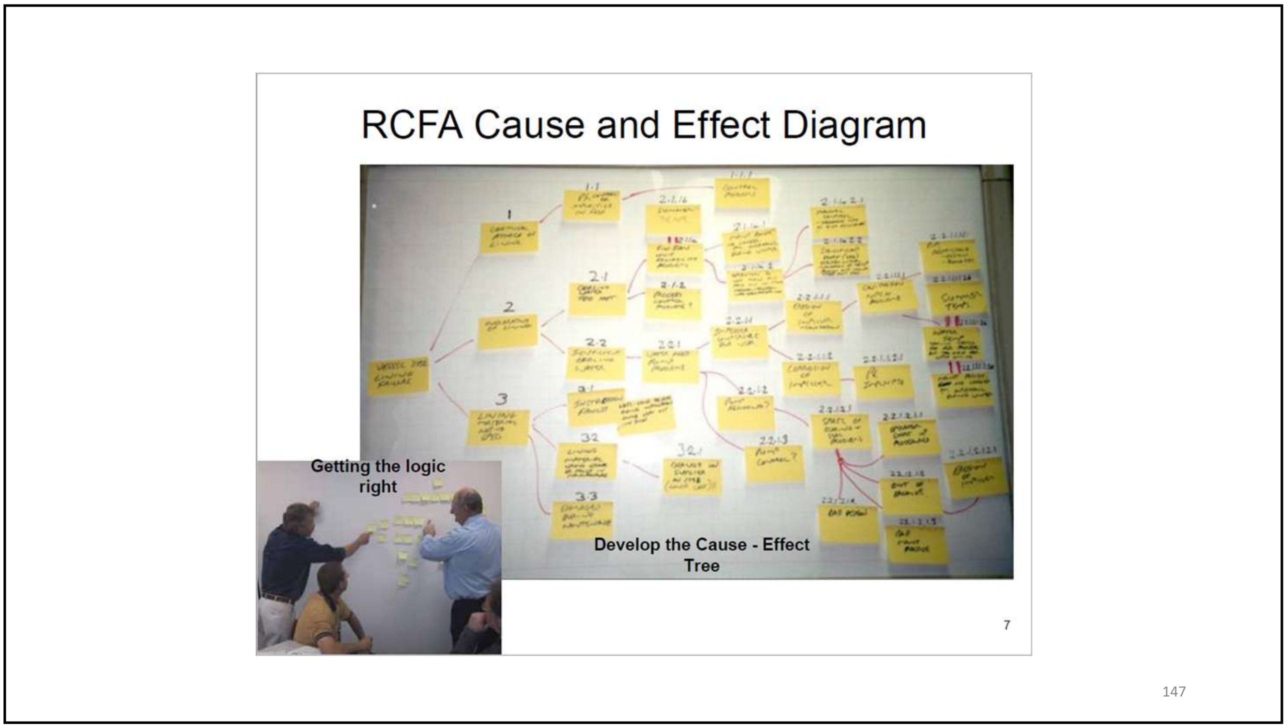
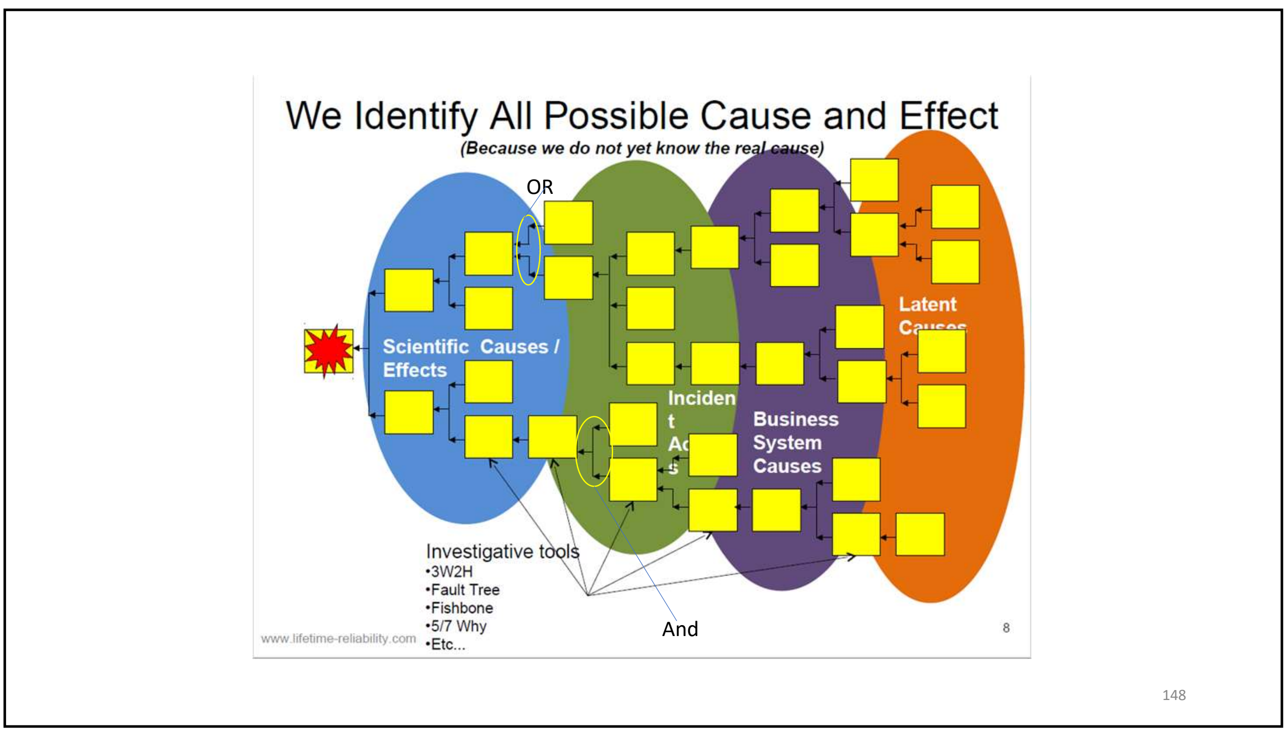

RCFA Cause and Effect Diagram
Getting the logic right
Develop the Cause - Effect Tree
7
147


We Identify All Possible Cause and Effect
(Because we do not yet know the real cause)
OR
Scientific Causes / Effects
Business System Causes
Latent Causes
Investigative tools
•3W2H
•Fault Tree
•Fishbone
•5/7 Why
•Etc...
And
www.lifetime-reliability.com
8
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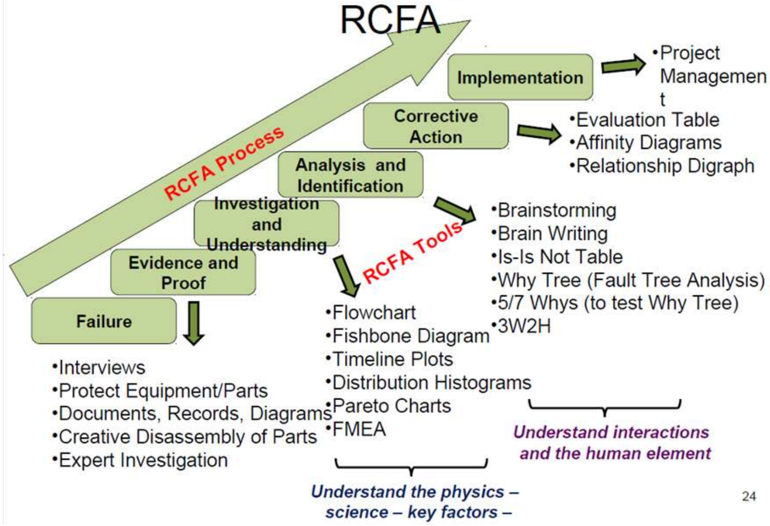
Tools to Use During Equipment Failure RCFA



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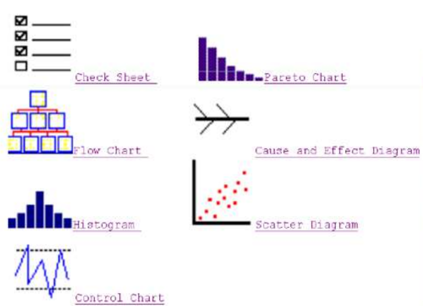
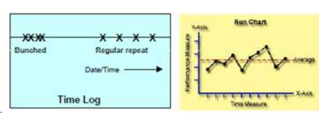
Data Analysis to Release Information





Is/ Is Not table to Compare Operation

Problem: high fuel consumption		Our car	Neighbour's car	Relative's car
Got the problem?		Yes	No	No
Similarities	All sedans			
	All Camry			
Differences	Age	10 yrs	1 yr	2 yr
	Petrol smell	Yes	No	No
	Driven by son	Yes	No	Yes
	Colour	Blue	Red	Red

Use Visual Analysis Tools for Patterns and Trends

30

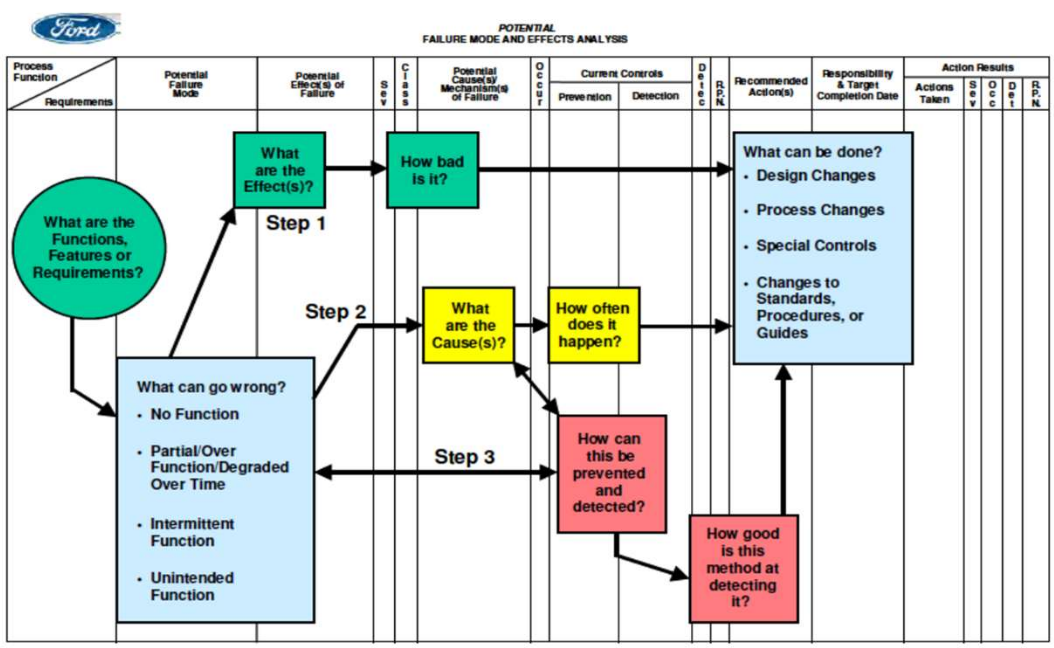
150

What is FMEA

FMEA: Failure Mode and Effect Analysis is a method designed to

- Identify and fully understand potential failure modes and their causes, and the effects of failure on the system or end users, for a given product or process.
- Assess the risk associated with the identified failure modes, effects and causes, and prioritize issues for corrective action.
- Identify and carry out corrective actions to address the most serious concerns

151



FMEA Hyper link

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FMEA Process

The failures are prioritized according to how serious their consequences are, How frequently that occur and How easily they can be detected. The purpose of FMEA is to take action to reduce or eliminate problems starting with the highest-priority ones

- Assemble a cross-section team
- Identify the scope of FMEA
- Fill in Identifying information of FMEA form
- Identify the function of your scope
- For each function identify the Ways It can fail, this will term as failure mode.
- For each failure mode Identify the consequences on the system
- Determining How serious is the effect
- For each failure mode determine the All Potential Root Causes
- For each cause determine the occurrence rating.
- For each root cause identify the current process control
- For each failure mode determine the detection rating.

FMEA Hyper link

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Various Quality Tools

- ✓ Affinity diagram
- ✓ Arrow Diagram
- ✓ Balance Score card
- ✓ Box plot
- ✓ Brain Storming
- ✓ Contingency diagram
- ✓ Control charts
- ✓ Correlation Analysis
- ✓ Cost of Poor quality Analysis
- ✓ Criterial filtering methods
- ✓ Critical to Quality analysis
- ✓ Decision Matrix
- ✓ Design of Experiment
- ✓ 5W2H
- ✓ Flow chart
- ✓ Force field analysis
- ✓ Gantt Chart
- ✓ Graphs
- ✓ Histogram and Other frequency Distribution
- ✓ Hypothesis testing
- ✓ Is-is Not matrix
- ✓ List reduction

- ✓ Matrix diagram
- ✓ Meeting Evaluation
- ✓ Mind Map
- ✓ Mistake proofing
- ✓ Multi Vari Chart
- ✓ Multivoting
- ✓ Normal probability plot
- ✓ Paired Comparison
- ✓ Pareto Chart
- ✓ performance Index
- ✓ PDCA Cycle
- ✓ Plan result Chart
- ✓ Potential problem analysis
- ✓ Prioritization matrix
- ✓ Process Capability index
- ✓ program decision program chart
- ✓ Project chart
- ✓ Radar chart
- ✓ Relation diagram

- ✓ Repeatability and Reproducibility Studies
- ✓ Requirement Table
- ✓ Requirement and Measure tree
- ✓ Run chart
- ✓ Scatter diagram
- ✓ SIPOC Diagram
- ✓ Stake holder Analysis
- ✓ Storyboard
- ✓ Stratification
- ✓ Survey

154

Reliability Centered Maintenance

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Reliability Centered Maintenance

Reliability-Centered Maintenance (RCM)—Any RCM process shall ensure that all of the following seven questions are answered satisfactorily and are answered in the sequence shown as follows:

- What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
- In what ways can it fail to fulfil its functions (functional failures)?
- What causes each functional failure (failure modes)?
- What happens when each failure occurs (failure effects)?
- In what way does each failure matter (failure consequences)?
- What should be done to predict or prevent each failure (proactive tasks and task intervals)?
- What should be done if a suitable proactive task cannot be found (default actions)?

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Reliability Centered Maintenance

Select the level of Analysis to be carried out

- The level of detail which is ultimately selected should enable a suitable failure management policy to be identified.
- Higher levels (less detail) should be selected if the component or sub-system is likely to be allowed to run to failure or subject to failure finding.
- Lower levels (more detail) need to be selected if the failure mode is likely to be subjected to some sort of proactive maintenance

Functions Complete Definitions

- primary functions, which summarize why the asset was acquired in the first place. This category of functions covers issues such as speed, out put, carrying or storage capacity, product quality and customer service .
- secondary functions, which recognize that every asset is expected to do more than simply fulfil its primary functions. Users also have expectations in areas such as safety, control, containment, comfort, structural integrity, economy, protection, efficiency of operation, compliance with environmental regulations and even the appearance of the asset

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Reliability Centered Maintenance

Functional failure

- Total inability to function
- Partial failures, where the asset still functions but at an unacceptable level of performance
- Clearly these can only be identified after the functions and performance standards of the asset have been defined.

Failure Modes

- All the events which are reasonably likely to cause each failed state. These events are known as failure modes. ‘
- Reasonably likely' failure modes include those which have occurred on the same or similar equipment operating in the same context,
- Failures which are currently being prevented by existing maintenance, and
- Failures which have not happened yet but which are considered to be real possibilities

Failure effects

- It describe what happens when each failure mode occurs . It include all the information needed to support the evaluation of the consequences of the failure.
- It is these consequences which most strongly influence the extent to which we try to prevent each failure.
- If a failure has serious consequences, we are likely to go to great lengths to try to avoid it.
- A great strength of RCM is that it recognizes that the consequences of are far more important than their technical characteristics.
- In fact, it recognizes that the only reason for doing any kind of proactive maintenance is not to avoid failures per se, but to avoid or at least to reduce the consequences of failure

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Reliability Centered Maintenance

The RCM process classifies these consequences into four groups, as follows:

- Hidden failure consequences: Hidden failures have no direct impact, but they expose the organisation to multiple failures with serious, often catastrophic, consequences. (Most of these failures are associated with protective devices which are not fail-safe.)
- Safety and environmental consequences: A failure has safety consequences if it could hurt or kill someone. It has environmental consequences if it could lead to a breach of any corporate, regional, national or international environmental standard.
- Operational consequences: A failure has operational consequences if it affects production (output, product quality, customer service Of operating costs in addition to the direct cost of repair)
- Non-operational consequences : Evident failures which fall into this category affect neither safety nor production.

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Reliability Centered Maintenance

Proactive Tasks

Proactive tasks are tasks undertaken before a failure occurs, in order to prevent the item from getting into a failed state[1]. They embrace what is traditionally known as ‘predictive’ and ‘preventive’ maintenance

RCM divides proactive tasks into three categories

- Scheduled Restoration Tasks
- Scheduled Discard Tasks
- Scheduled On-condition Tasks

Scheduled restoration entails remanufacturing a component or overhauling an assembly at or before a specified age limit, regardless of its condition at the time .

Scheduled discard entails discarding an item at or before a specified life limit, regardless of its condition at the time.

On-condition task :

- Some functional attribute is monitored continuously and an alarm is raised when monitored attribute values crosses set value.
- The majority of these techniques rely on the fact that most failures give some warning of the fact that they are about to occur. These warnings are known as potential failures
- Potential failures defined as identifiable physical conditions which indicate that a functional failure is about to occur or is in the process of occurring.

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Reliability Centered Maintenance

Default Actions

RCM recognizes three major categories of default actions, as follows:

- Failure-finding: Failure-finding tasks entail checking hidden functions periodically to determine whether they have failed (whereas condition based tasks entail checking if something is failing).
- Redesign: Redesign entails making any one-off change to the built-in capability of a system. This includes modifications to the hardware and also covers once-off changes to procedures.
- No Scheduled Maintenance: This default entails making no effort to anticipate or prevent failure modes to which it is applied, and so those failures are simply allowed to occur and then repaired. This default is also called run-to-failure.

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Maintenance Task Selection

For hidden failures (The Failures which are not evident By their own) A proactive task is worth doing if it reduces the risk of the multiple failure associated with that function to an acceptably failure low level. If such a task cannot be found then a scheduled failure finding -task must be performed. If a suitable failure-finding task cannot be found, then the secondary default decision is that the item may have to be redesigned (depending on the consequences of the multiple failure) .

For failures with safety or environmental consequences A proactive task is only worth doing if it reduces the risk of that failure on its own to a very low level indeed, if it does not eliminate it altogether. If a task cannot be found which reduces the risk of the failure to an acceptably low the item must be redesigned or the process must be changed.

Failure with operational consequences, A proactive task is only worth doing if the total cost of doing it over a period of time is less than the cost of the operational consequences and the cost of repair over the same period. In other words, the task must be justified economic no scheduled grounds. If it is not justified, the initial default decision is maintenance. (If this occurs and the operational consequences are still unacceptable then the secondary default decision is again redesign).

Failure with non-operational consequences A proactive task is only worth doing if the cost of the task over a period of time is less than the cost of repair over the same period. So these tasks must also be justified on economic grounds. If it is not justified, the initial default decision no scheduled maintenance, is again and if the repair costs are too high, the secondary default decision is once again redesign .This approach means that proactive tasks are only specified for failures which really need them, which in turn leads to substantial reductions in routine workloads

Compare this with the traditional approach to the development of maintenance policies. Traditionally, the maintenance requirements of each asset are assessed in terms of its real or assumed technical characteristics , without considering the consequences of failure. The resulting schedules are used for all similar assets, again without considering that different consequences apply in different operating contexts. This results in large numbers of schedules which are wasted, not because they are 'wrong' in the technical sense, but because they achieve nothing.

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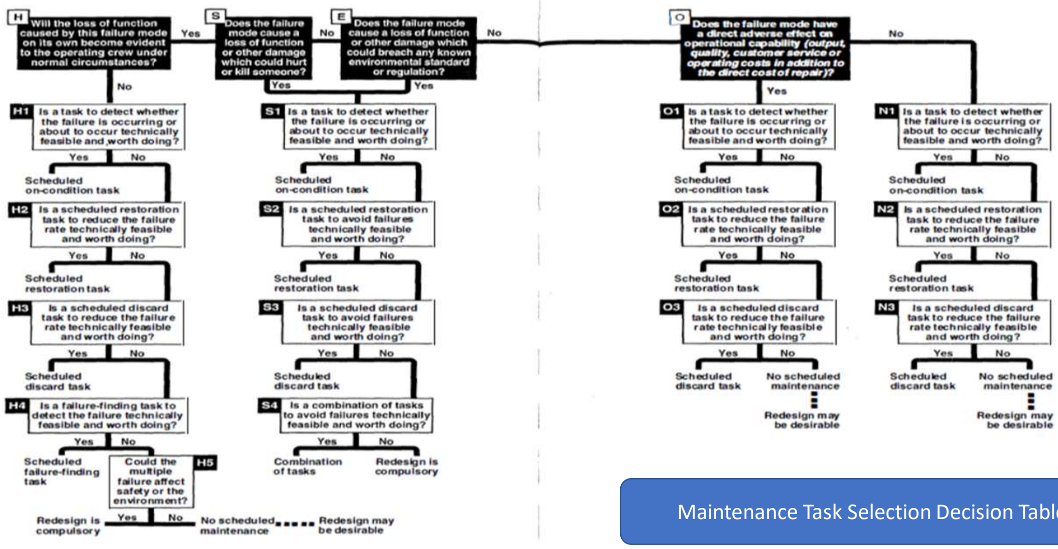
Maintenance Task Selection



Maintenance Task Selection Decision Table

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Maintenance Task Selection

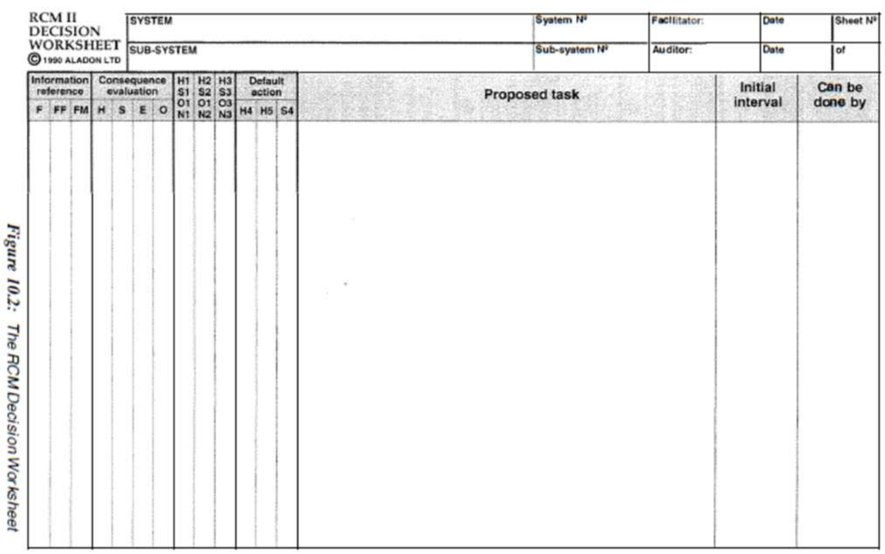

Figure 10.2: The RCM Decision Worksheet

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Develop Equipment Preventive Maintenance

- Identify the type and purpose of the equipment, as well as its service life expected lifespan, performance and reliability.
- Determine the maintenance objectives and criteria, such as availability, efficiency, quality, safety, cost, etc.
- Identify the sub-assemblies of the equipment and their functions. For example, an equipment may have a hydraulic System, Reduction gearbox with Belt and pully driven system, Fluid pump, Pneumatic control system and Electrical panel.
- We can have sub assembly boundary system roughly covering full equipment
- Assess failure mechanism and material degradation associated with the elements of Subassembly, such as fatigue. Wear & tear, corrosion, erosion and immediate environment impact such as heat, dust, moister, vibration etc.
- For each sub-assembly, determine the maintenance procedure and frequency based on the manufacturer's recommendations, the operating conditions, and your own history of Break downs
- Select the appropriate maintenance strategy and methods, such as preventive, predictive, corrective, condition-based, etc. Understanding of RCM can help here.
- Define the maintenance tasks and activities, such as inspection, testing, cleaning, lubrication, adjustment, repair, replacement, etc.
- Determine the maintenance frequency and estimate time duration, necessary resources and personnel for the maintenance execution, such as tools, spare parts, manuals, technicians for work plan.
- Aggregate the maintenance procedures for all the sub-assemblies and create a maintenance task list that covers the entire equipment

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Start Your Preventive Maintenance

Equipment Name:___________________ **Equipment Number:**___________________

SubAssembly	Sub Subassembly	Component	Failure Mode	Failure Mechanism	Existing Control	Progressive or Catastrophic(and Ease of Detection)	if Progressive what technology can be used to detect	Time or uses bases plans	Insurance Spare

- Equipment
- Subassembly
- Sub Subassembly
- Component
- Failure Mode
- Failure Mechanism
- Existing Control
- Progressive or Catastrophic(and Ease of Detection)
- if Progressive what technology can be used to detect
- Time or uses bases plans
- Insurance Spare

Role Responsibility and Accountability Matrix

Responsible (R): The person or group who is responsible for completing a specific task or activity. They are directly involved in the execution of the task and are accountable for its completion.

Accountable (A): The person who has ultimate ownership and decision-making authority for a particular task or activity. This person is answerable for the results and outcome of the task.

Supportive (S): Individuals or groups who provide assistance, resources, or expertise to help the responsible person complete the successfully. They are not directly responsible for task the task but contribute to its execution.

Informed (I): Individuals or groups who need to be kept informed about the progress, decisions, or outcomes of a task or activity. They are not directly involved in execution but require updates to stay informed.

Consulted (C): Individuals or groups whose input or expertise is sought before decisions are made or actions are taken. Their insights are considered during the decision-making process.

	Responsibility	Accountability	Support	Information	Consultation
Maintenance Manager					
Maintenance Engineer					
Production Engineer					
Quality Engineer					
Maintenance Operator					
Production operator					
Logistics					

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Maintenance Planning and Scheduling Processes

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What is Maintenance Planning and Scheduling

Strategic Maintenance Planning: It involving the selection of maintenance strategies from among alternative courses of action, for the enterprise as a whole. It is about deciding in advance what maintenance types to use to manage the various operating risks of the organization. This is what the Maintenance Manager is responsible to do

Operational Maintenance Planning; It is the process of establishing the sequence and relationship among task elements and providing the parts and resources needed to deliver the work plan.

Scheduling is the process of determining which jobs get worked on, when and by whom, based on the priority, the resources, and asset availability. The scheduling process should take place before the job is executed.

Work Execution and Completion

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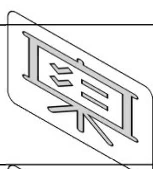
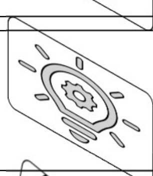
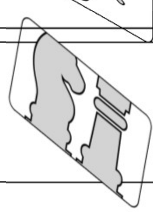
What is Planning



Definition: Planning is the fundamental management function, which involves **deciding beforehand**, what is to be done, when is it to be done, how it is to be done and who is going to do it.



It is an **intellectual process** which **lays down** an **organization's objectives and develops various courses of action**, by which the organisation can achieve those objectives. It chalks out exactly, how to attain a specific goal.



Planning is nothing but **thinking before the action takes place**. It helps us to take a **peep into the future** and decide in advance the way to deal with the situations, which we are going to encounter in future. It involves logical thinking and rational decision making.

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Planning Characteristics

Managerial function: Planning is a first and foremost managerial function provides the base for other functions of the management, i.e. organizing, staffing, directing and controlling, as they are performed within the periphery of the plans made.

Goal oriented: It focuses on defining the goals of the organisation, identifying alternative courses of action and deciding the appropriate action plan, which is to be undertaken for reaching the goals.

Pervasive: It is pervasive in the sense that it is present in all the segments and is required at all the levels of the organisation. Although the scope of planning varies at different levels and departments.

Continuous Process: Plans are made for a specific term, say for a month, quarter, year and so on. Once that period is over, new plans are drawn, considering the organization's present and future requirements and conditions. Therefore, it is an ongoing process, as the plans are framed, executed and followed by another plan.

Intellectual Process: It is a mental exercise at it involves the application of mind, to think, forecast, imagine intelligently and innovate etc.

Futuristic: In the process of planning we take a sneak peek of the future. It encompasses looking into the future, to analyze and predict it so that the organisation can face future challenges effectively.

Decision making: Decisions are made regarding the choice of alternative courses of action that can be undertaken to reach the goal. The alternative chosen should be best among all, with the least number of the negative and highest number of positive outcomes.

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Planning Process

Define the problem or opportunity: Identify the current situation, the desired future state, and the gap between them.

Analyze the situation: Gather relevant data and information, identify the root causes of the problem, and assess the strengths, weaknesses, opportunities, and threats (SWOT) of the situation.

Generate alternatives: Brainstorm possible solutions or courses of action, and evaluate their feasibility, effectiveness, and potential impacts.

Select the best alternative: Compare and rank the alternatives based on criteria such as cost, benefit, risk, and alignment with the goal or vision.

Implement the plan: Develop a detailed action plan with specific tasks, responsibilities, resources, timelines, and milestones. Execute the plan and monitor its progress and performance.

Evaluate the results: Measure the outcomes and impacts of the plan against the predefined criteria and indicators. Identify any deviations or problems, and take corrective actions if needed. Review and document the lessons learned and best practices for future reference.

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Benefits of Planning

Planning helps you clarify your vision and purpose. By setting specific, measurable, achievable, relevant and time-bound (SMART) objectives, you can focus on what matters most and align your actions with your values.

- Planning helps you manage your time and resources efficiently. By breaking down your tasks into smaller steps and prioritizing them, you can avoid procrastination and waste. You can also allocate your budget, materials and human resources accordingly.

- Planning helps you anticipate and mitigate risks. By identifying potential challenges and opportunities, you can prepare contingency plans and backup solutions. You can also monitor your progress and adjust your plan as needed.

- Planning helps you communicate and collaborate effectively. By sharing your plan with others, you can get feedback, support and buy-in from your stakeholders. You can also delegate tasks and coordinate with your team members to achieve synergy.

- Planning helps you improve your performance and quality. By setting standards and criteria for your outcomes, you can evaluate your results and learn from your mistakes. You can also celebrate your achievements and reward yourself and others for their efforts.

- Planning helps you reduce stress and increase satisfaction. By having a clear plan, you can reduce uncertainty and anxiety. You can also enjoy the process of planning and executing your plan, as well as the sense of accomplishment when you reach your goals.

- Planning helps you grow and develop personally and professionally. By planning, you can challenge yourself to stretch beyond your comfort zone and acquire new skills and knowledge. You can also reflect on your experiences and apply your learning to future situations.

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Barriers Hindering Planning Process

Dynamic and Complex Environments: Changes in any of the elements of an organization's task or general environments can radically alter the plans and obstruct the entire planning process. (Incidentally this also main reason to do Planning)

Reluctance to Establish Goals: Reluctance on the part of some managers to establish goals for themselves and their units due to lack of confidence or fear or failure

Lack of planning skills Planning is not natural a natural tendency for most of the persons specially in current complex environment. Lack of understanding of planning frameworks tools and methods also leads to poor attitude toward planning.

Lack of an Appropriate 'Planning Climate : The lack of an appropriate 'planning climate' within the organisation as a whole. There may be lack of top management support. The manager's superiors may, for instance, be perceived as being uncommitted or even hostile to planning and to the use of objectives.

Procedural inflexibility (which can weaken the effectiveness of planning) and continued pressure on line managers to act quickly, so there is not sufficient time to prepare effective plans, may create severe problems for those who have to forecast and act according

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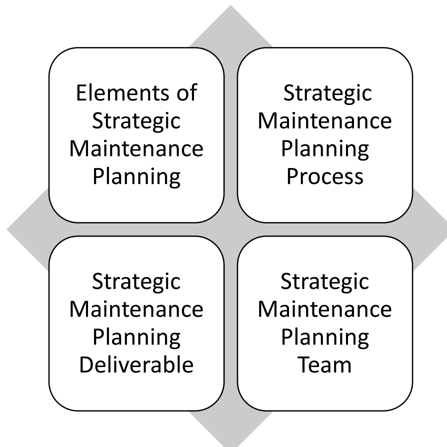
Strategic Maintenance Planning



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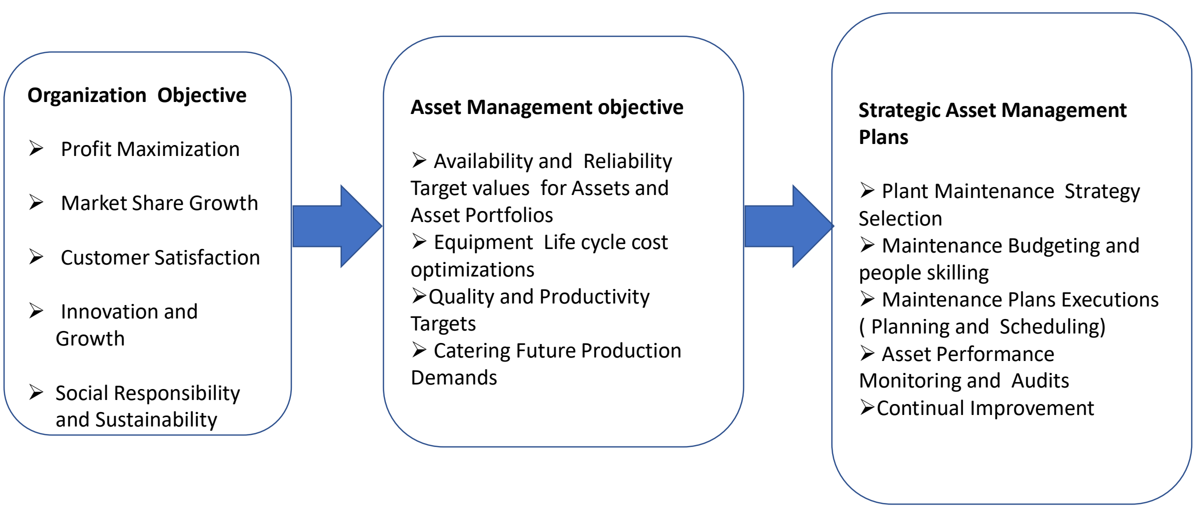
Maintenance Alignment with Organizational Objectives



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Maintenance Alignment with Organizational Objectives

Organization Objective

- Profit Maximization
- Market Share Growth
- Customer Satisfaction
- Innovation and Growth
- Social Responsibility and Sustainability

→

Asset Management objective

- Equipment Reliability
- Risk reduction
- Defect Elimination
- Least operating cost
- Maximum Production
- Failure Avoidance

→

Asset Management Tasks

- Break down Maintenance
- Corrective Maintenance
- Preventive Maintenance
- Predictive maintenance
- Proactive Maintenance
- Spare parts Management
- Maintenance Budgeting
- Manpower Budgeting and Skilling
- Asset Management Knowledge creation and Management

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Objective Hierarchies

Approach A

✓Equipment Reliability
✓Risk reduction
✓Defect Elimination
✓Failure Avoidance
✓Maximum Production
✓Least operating cost

↓

✓ Systematic , They have overlapping work plans for time horizons.
✓ Drawing guidance from Lag and leading Key performance indicator. They are more in control of situations.
✓ Improved production

Approach B

✓Maximum Production
✓Least operating cost
✓Failure Avoidance
✓Risk reduction
✓Defect Elimination
✓Equipment Reliability

↓

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Element of Strategic Maintenance Planning

Element of Strategic Maintenance Planning

SMP carried out to achieve Median & long-term objective of Organizations.

The Strength of SMP shall match level of risk of Equipment Failure

SMP are guided by organization Asset Policy Stated, Implied, (may be conflicting) Exercise: what is your plant's Asset Policy

The SMP shall abide by financial constrained but make a case of cost optimization

The organization shall have consistent risk evolution methodologies and mitigation approaches

SMP should be documented at a level that is appropriate to the organization and the degree of sophistication in its asset management approach.

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Strategic Maintenance Planning Objective

- Reducing downtime and operational costs by preventing breakdowns and failures
- Improving safety and quality by ensuring compliance with standards and regulations
- Enhancing customer satisfaction and loyalty by delivering consistent and reliable service
- Increasing asset life cycle and value by preserving and improving their condition
- Supporting strategic goals and objectives by aligning maintenance activities with organizational vision and mission

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Strategic Maintenance Planning Process

- Prepare a list of asset systems and their constituent assets, and gather information about them
- Identify risks: create a table of potential events and their impacts and includes risks to the delivery of the organizational objectives
- Identify risk controls that exist
- Analyze risks using appropriate process.
- Evaluate the level of risk: estimate the likelihood and consequences for each potential event
- Evaluate the level of risk over time: where appropriate, establish whether the identified risks will change over time, and how this will affect their consequences.
- Evaluate the tolerability of the risks (if any) are sufficient to keep the risks under control and to meet any legal, statutory and other asset management requirements.

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Strategic Maintenance Planning Deliverable

- Maintenance objectives: The desired outcomes and benefits of maintenance activities, such as improving reliability, availability, safety, performance, and compliance.
- Maintenance scope: The identification and classification of the assets that are subject to maintenance, as well as the criteria and methods for prioritizing and selecting them.
- Maintenance approach: The definition and description of the maintenance tactics, techniques, and tools that are applied to the assets, such as preventive, predictive, corrective, or condition-based maintenance.
- Maintenance resources: The estimation and allocation of the human, financial, and material resources that are required to execute the maintenance activities, as well as the roles and responsibilities of the maintenance personnel and stakeholders.
- Maintenance performance: The establishment and measurement of the key performance indicators (KPIs) that are used to monitor and evaluate the effectiveness and efficiency of the maintenance activities, as well as the identification and management of the risks and opportunities associated with them.
- Maintenance improvement: The identification and implementation of the improvement actions that are aimed at enhancing the maintenance processes, practices, and outcomes, as well as the review and update of the SMP based on feedback and lessons learned

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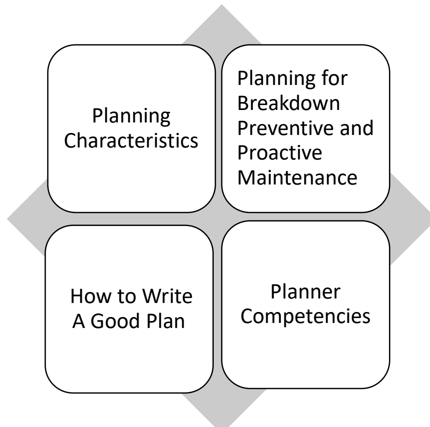
Maintenance Operational Planning... Simply Planning



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Maintenance Planning   Definition and Benefits

- The process of job planning encompasses verification of all aspects of the job to be done as well as identification of the various input resources required to complete each job in an orderly manner .

- Planning is the process of determining the resources and method needed to perform maintenance work efficiently and effectively. Planning Defines what and How. Planner develops a work plan to repair or perform a CM or PM for asset the plan include work description task sequence material and tool requirement work crew skill set and safety requirement.

- A work plan is the key deliverable of the planning process. This area is where the most gains in productivity can be made

- Every hour invested in planning saves 1-3 hours in work execution.

- **More wrench time**: By planning ahead, maintenance workers can spend more time on actual repairs and less time on waiting for parts, tools, permits, or instructions.

- **Work completion within estimates**: By having a clear plan and scope of work, maintenance workers can avoid delays, rework, or scope creep that can increase the cost and time of the project.

- **Higher quality and reliability**: By following a standardized and documented procedure, maintenance workers can ensure that the work is done correctly and consistently, reducing the risk of errors or failures.

- **Improved safety and compliance**: By adhering to the best practices and regulations, maintenance workers can prevent accidents, injuries, or violations that can harm themselves, the equipment, or the environment.

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MAINTENANCE WORK PACK MINIMUM CONTENT		
ITEM No	DESCRIPTION	COMMENTS
1	Job Plan	The work flow process diagram of job milestones in line-of-sight detail.
2	Skills / Competencies required	The expertise and competencies needed to do the job correctly
3	Job Procedure	Task by task fully detailed description with quality standards and corrective action.
4	All Drawings relevant to the job	Could be mechanical, electrical, civil, structural, process diagrams, etc.
5	Bill of Materials for the job	The parts used in the job including part number, part description and quantity required
6	Tools List for the job	The tools needed to do the job safely and correctly
7	Equipment List for the job	Include the equipment specification e.g. Franna Crane 20T, Mobile Air Compressor 150 CFM, two-man elevated work platform, etc.
8	Settings / Set Points	For calibration and adjustment.
9	Inspection and Test Plan with Quality Standards	Pass/Fail criteria for each task. Includes providing tolerances and condition criteria to confirm a part can remain in-service or is to be replaced.
10	Data Sheets of the equipment	Information on the design and service specifications.
11	Record Sheets	A place to make a record of an observation or measurement as proof. Often satisfied with an Inspection and Test Plan.
12	Calculation Sheets	A place to do the calculation laid-out in the sequence of the calculation with space for the figures and an example of a correct calculation.
13	All Permits and Tags	Safety, environmental, disposal, transport heritage, plant handover, etc approvals
14	Risk Assessment Forms	Site risk assessment and management documents.
15	All Technical Tables	Copies of manufacturer data tables or international engineering tables highlighted to show the information applying to the job.
16	Special Requirements	Instructions and particulars specific to the job that must be observed.
17	Commissioning Plan	Controlled testing to confirm proper operation.
18	Parts and Materials	All parts and materials are identified and gathered together in one location
19	Proof Test Recording Sheet	A check sheet to note the proof test results for each job plan activity that confirms work quality is achieved
20	Failure Mode and Equipment Health Report	A record of the Technicians observations and decisions and photographic evidence of failure modes

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Symptoms of Ineffective Planning

- Maintenance people standing around waiting on parts
- High rework
- Poor work performance
- High stockout in the storeroom
- Planners being used to expedite parts
- Maintenance personnel arriving at the job site and waiting for the asset / system to be shut down (wait is over 15 minutes)
- Frequent trips to storeroom by maintenance personnel
- Production downtime always more than estimated

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Planning for Breakdown Maintenance

[redacted]
maintenance
approaching.

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Planning for Breakdown Maintenance

- To the extend possible ready assemblies shall be kept for machines and shall used during breakdown rectification, faulty assembly can be corrected afterword.
- Availability of common stock for replacement or diagnosis purpose shall be available at store and can be withdrawn with minimum efforts.
- It is to be ensured that craftsman shall carry all required tool to equipment under breakdown and they have provision to carry all at a time.
- Supervisor/ Shift in-charge must take electrical Isolation and other safety precautions.
- A copy of Machine panel drawings, A set of fuse, relays and similar other provision can be kept in panel for quick diagnosis.
- Tradesmen shall be trained for best approach to diagnosis common problems.
- A machine operator with fair knowledge of equipment mechanisms can be serve as good resource for Fault diagnosis. Maintainer shall share knowledge with operators.
- Work-order shall be closed with all required details and maintainer or operator must provide feedback for quicker resolution or lesson learned.
- All efforts shall be made to capture work order information and feedback in CMMS or otherwise computerized sheet.
- A trigger for why-why analysis shall be embedded in work request/ workorder closer (e.g. Breakdown > x Hours or repeat break down)

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Planning for Preventive and Predictive Maintenance

- Details task list shall be made with special emphasis on test method, or measurement to check job done as per standards. Critical measurement/ inspection shall be supervised by engineer or designated person and must be signed. Wherever warranted photos shall be taken or values to be noted down
- Individual or group task time estimation with +- 15 % range.
- Determine number of analyze craftsman and their respective skills.
- Determine if Special tools , provisions , lifting- shifting arrangement required.
- All relevant SOPs manuals, Drawings and report from Previous Preventive Maintenance shall be kept ready for ready reference
- Line up with external service provider with clear scope of work (As required)
- Machine history shall be reviewed to check break-down and preventive maintenance activities carried out earlier and if any work-order is pending .
- if subject equipment indicate any repetitive breakdown, due-diligence-Inspection or test shall be planed with preventive task List
- Ensure replaceable spares consumable availability and reserve them for subject plan.
- List of work permit, LOTO shall be part of work pack
- For Predictive maintenance vibration pick up points shall be clearly Indicated on data Capturing Sheet.

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Planning for Proactive Maintenance

- Proactive maintenance task as generated as the result of RCA, CAPA and CBM Risk based Inspection or design out activities
- Its predominately include new design, material Selections, procurement of spares, hiring services of external expertise, assemblies and trials. Due diligence shall be paid at each step.
- Once all prerequisites are ready and verified for " as per design and quality attributes" , further process shall be developed for its execution.
- Proactive maintenance jobs are as on of there own kind all care must be taken so not to miss any step or critical inspections/ observation. Planner must take help of Supervisor or senior craftsman while preparing such procedures.
- Individual or group task time estimation with +- 15 % range.
- Determine number of analyze craftsman and their respective skills.
- Determine if Special tools , provisions , lifting- shifting arrangement required.
- All relevant SOPs manuals, Drawings and report from Previous Preventive Maintenance shall be kept ready for ready reference
- Line up with external service provider with clear scope of work (if required)
- Machine history shall be review to check break down and preventive maintenance activities carried out on equipment also if any other corrective order is pending against/ PM schedule is approaching.
- if subject equipment indicate any repetitive breakdown in nature as informed by planner or otherwise, due-diligence-Inspection or test shall be planed with preventive task List
- Ensure replaceable spares consumable availability and reserve them for subject plan.
- List of work permit, LOTO putting required signage and informing operators of nearby equipment shall be part of work pack

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Planner Competencies

Core Competencies Required for Planner's Work

- **Fully certified to perform relevant maintenance activities e.g. applicable licenses, permits and qualifications**
- **Sound and correct understanding of equipment reliability concepts**
- **Solid appreciation of risk management strategy and practices related to plant and equipment**
- **Solid appreciation of quality management methods and practices related to plant and equipment**

Planning capabilities can be enhanced by ensuring the following:

- **Employee involvement and roles. Educate all maintenance stakeholders from a plant manager to the maintenance technician in P&S process to ensure all players understand their role.**
- **It is recommended that a senior maintenance technician may be assigned to the maintenance planners for few hours a day. planning support job is a good practice.**
- **Maintenance planners must have a library of information including equipment manuals, drawings, specifications, and specific equipment manufacturer's libraries.**
- **Planners shouldn't perform additional duties such as temporary or relief supervisors, safety or environmental representative.**
- **The planner is not a secretary or clerk. Planners shouldn't expedite parts for breakdowns or problems. Their responsibility is to insure that future work is planned properly so it can be executed effectively.**
- **Planned work package, should be reviewed by a craft supervisor to validate that the work package is do-able as planned before scheduling**

How to write Maintenance task description

- The planner shall visit the facility/ equipment where work is to be planned.
- Outline the task to done and list out provisions to be required for work completion Wherever warranted shall take help from senior craftsman or supervisor.
- Use template to articulate the
- Safety Requirements
- Job sequence
- Job details
- Spare part requirements
- Estimated times
- Craft Trade wise Man Hours required
- Drive Material and Manpower Cost as required
- All efforts shall be made to provide methods of proof test against each task undertaken wherever applicable standard shall be provided with task list.
- To Possible extend these task list shall made modular and indexed for easy retrieval and reuse.
- For repetitive task (Preventive Maintenance) , feedback from previous works shall be suitably added to task list.
- Effectiveness of these Plans shall be checked during work executions and work completion.

192

How to write Maintenance task description

Duties	Performance Levels		
	GOOD	BETTER	BEST
Establish, maintain and improve the Maintenance Planning and Scheduling business flow process	Detailed flow diagram of planning and scheduling business processes with all necessary interactions required and persons involved	Process flow diagram steps are explained in supporting documents indicating the performance criteria to be met for each stage on the process	Fully documented quality system with clearly established performance targets, deadlines, outcomes, responsibilities and authorities identified for every stage and everyone involved in the process
Scope the full extent of maintenance work needed to conduct the relevant repair / preventive / predictive / design-out activities on the organization's plant and equipment	Provide a work pack with job planning sufficiently detailed to prevent work errors, with all equipment safety issues highlighted to the technician and the correct maintenance documents and parts are available so that the maintenance work performed returns machine condition to as-good-as-new	Fully detailed and complete job pack with clear measures of maintenance work quality with monitoring tests to prove the work meets that quality. All parts collected together in a pre-assembled and checked package made available to the technician.	Top quality content work pack covering all equipment safety, reliability, parts condition and work quality proof-tests so that the maintenance work performed delivers substantial equipment reliability growth. Quality parts correctly identified, pre-assembled, protected and checked for correctness delivered to the work front awaiting the technician
Develop cost and time estimates of planned maintenance work	Within 20% of actual job cost and actual job time	Within 15% of actual job cost and actual job time	Within 10% of actual job cost and actual job time

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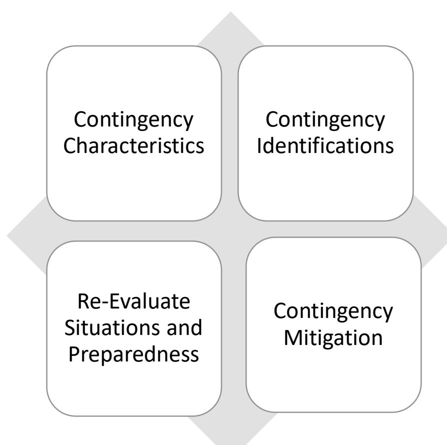
Contingency Planning and Mitigation



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Contingency Planning

Generally these are of cases of too low probability and very high impact.

A well-written equipment breakdown contingency plan will provide a planned response to recover from events that result in a forced outage which impacts production and facility equipment.

Contingency plan is a plan of action for a facility. It is intended to be used following a forced outage when a natural disaster, primary utility/services failure or critical/key equipment failure causes an unplanned loss of production.

Identification project can be allocated to Engineers for initial work out and afterward can be refined by team of experts

Examples

- Underground HT/ LT cable Failures
- Failure of Bottleneck Process
- Non availability of electrical supply from utility provider

195

Contingency Identification Process

- List all critical utility and plant essential services; list every critical object in each department.
- For each key/critical equipment and service, try to determine what events, problems or trends could potentially come up
- Departmental team shall determine the process or business impact in case a negative event, problem or occurrence takes place
- These departmental level contingencies shall be assembled in plant wide contingency list
- It shall also check for business impact if some of these contingencies falls simultaneously
- A central team shall evaluate each contingency and quantify the risk as per predetermine methods or procedure
- A list of contingency with prioritization shall be workout for mitigation planning

196

Contingency Mitigation Process

Identify preventive controls: Measures taken to reduce the effects of equipment or service disruptions can increase system availability and reduce contingency life cycle costs.

Create contingency strategies: Thorough recovery strategies ensure that production may be re-established quickly and effectively following a disruption.

The contingency plan should contain detailed and Specific guidance and procedures for efficiently repairing or replacing damaged equipment or restoring services.

Contingency plans shall estimate the resource requirements and base calculations for management approval

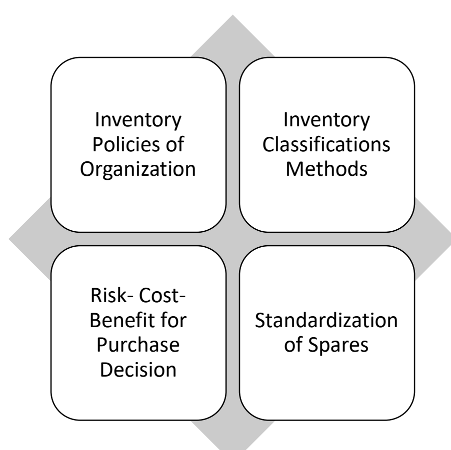
The contingency plan should be a living document that is reviewed regularly and updated as required to remain current with equipment enhancements and organizational changes

Example of External Agencies Required, water, natural gas or other fuel source utility suppliers, Critical equipment repair firms/contractors, /Server support

Example of External Agencies Required Original equipment suppliers Rental equipment sources

197

Material Planning and Maintenance Spare optimizations



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Inventory Policies of organization

Inventory Management Policies of organization

- A Clear maintenance Inventory policies and thereof approval procedures and authorities shall be defined .
- The Policy shall consider
  - Organization Short term and long term Objective
  - Aging of Subject Assets
  - Nature of Production process
- Predominant mode of Maintenance or Maintenance Strategies
- Maintenance Budgets

199

Inventory Classification

- ABC analysis : Usage Value (Consumption X price per unit)
- HML analysis : High-Medium- Low unit price
- VED analysis : Vital-Essential-Desirable. Criticality of the item
- SDE analysis : Scarce-Difficulties-Easy (Procurement Difficulties)
- GOLF analysis : Government Ordinary Local foreign source of procurement
- SOS Analysis : Seasonal -Off Seasonal
- FSN analysis : Fast-Slow-Non Moving Material Consumption
- XYZ Analysis : Total Inventory investment

Risk- Cost-Benefit Analysis for Inventory Decision

RCM Analysis (FMEA Analysis) lead Spare policy FMEA Sheet

BOM Analysis Individual component or component class shall be reviewed for failure mode Frequencies Its vulnerability to production process. Hyperlink Excel Sheet

Past Consumption Data normalized to current production scenario.

Maintenance Material Budgets will also helpful for inventory decisions

(Keep strong methods to capture day to day data, their retention, and to act upon)

201

Standardization of Spares

Benefits of Standardization

Leverage purchasing power: Buyers benefit from suppliers' economies of scale as they have the purchasing leverage to order bulk quantities of standardized spares and to obtain just-in-time support from suppliers.

Holding fewer inventories: Parts standardization offers reduced inventory levels because buyers can obtain the standardized parts directly from suppliers as they are identified and already listed across supplier websites/catalogues.

Cost reduction: Buyers can arrange for a spontaneous resupply of parts and materials from their suppliers whenever equipment downtime occurs, which results in cost reduction.

Less mistakes while processing orders

Reduces events of Stockouts

Better know-how-of standard Spare (Comparison to Multiple Variant)

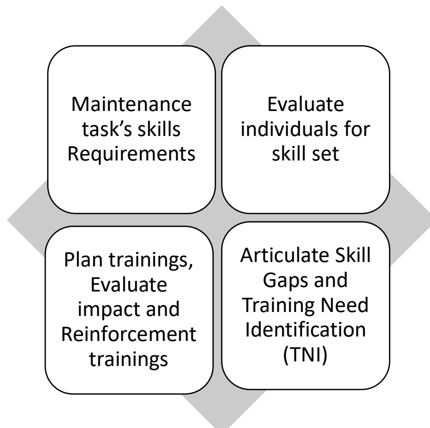
How to Standardize Spare

New Equipment orders shall Include Brand and model of common components Say Electricals, Hydraulic, Rubber items , Flexible piping , Electronics cards, PLC Etc..

On quarterly Basis Target shall be set to modified few machines to adapt common spares

202

Staff and Craftsman upskilling Planning



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Skill Evaluation process for Maintenance team

- List out Major Skills and competency required to do Routine maintenance works, Preventive Maintenance works Major repair works and Machine fault Diagnostics.
- Craftsman shall be evaluated for degree of Knowledge they have for a particular skill and accordingly classified to say Hydraulics, PLC controls
- The Skill gaps shall be identified as part of TNI Training Need Identifications
- Monthly or Quarterly classroom/On Job training (OJT) based training programs shall be conducted to upgrade individual skills.
- Craftsman shall be examined for theoretical and practical knowledge
- As required "reinforcement-Training" shall be provided":
- Skill : Know- How to solve a problem; Competency Along with Know – How of problem solving the doer must able to apply in real world situations.

204

Knowledge body required for Equipment Maintenance Team

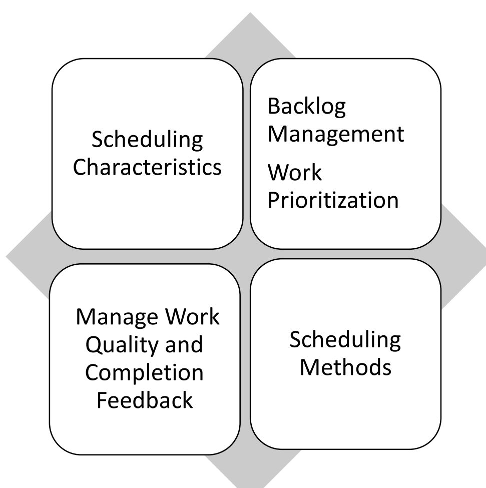
Craftsman
- ✓ Bearing Maintenance
- ✓ Bearing Fitment and removal Practice
- ✓ Right Lubrication Practices
- ✓ Mechanical drive maintenance
- ✓ Hydraulic Diagnosis and maintenance
- ✓ Pneumatic Controls
- ✓ Assembly/Disassembly procedures
- ✓ Leveling and Alignment of Machines
- ✓ Servicing/ Cleaning of Static equipment

Engineers & Supervisor
- ✓ Design consideration of Equipment
- ✓ Work Standards and precision Maintenance
- ✓ Mechanical Fits and Tolerance
- ✓ Root Cause Analysis
- ✓ Reliability Engineering
- ✓ Elements of Maintenance Planning and Scheduling
- ✓ Maintenance Management System
- ✓ Understanding of Lead and Lag KPIs and Maintenance data analysis

Maintenance Managers
- ✓ Asset Management Frameworks
- ✓ Evaluate risk out of various scenarios and setting the acceptable level of risk
- ✓ Aligning Maintenance Strategy with production requirements
- ✓ Optimum Maintenance Strategy for Equipment
- ✓ Design Machine Modifications
- ✓ Managing asset life cycles

205

Maintenance Work Scheduling



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Scheduling Characteristics

Scheduling is a joint maintenance and operations activity in which maintenance agrees to make resources available at a specific time when the asset can be also made available by the operations.

Scheduling ensures that resources — personnel, material and the asset on which the job is to performed — will be available for maintenance at a specified time and place

The scheduling is a tool for lining up jobs waiting to be performed so that operations are best served while maintenance also makes optimal use of its resources.

Production and Maintenance coordination maximizes the use of "windows of opportunity" to accomplish work whenever and wherever equipment is not in use.

In selecting jobs for the Weekly Master Schedule, it must first be ensured that all preventive and predictive routines are scheduled at their predetermined frequencies

Any jobs that cannot be scheduled to meet those dates should be discussed with the Requestor in the context of other job priorities established by all attendees

Conflicts between internal customers must be resolved by their common manager in the optimal interest of the overall operation.

207

Scheduling Principles

Doc Palmer, a noted authority in the area of Maintenance Planning and Scheduling, cites six basic scheduling principles:

Job plans shall provide necessary skills and respective man-hours for a task for effective scheduling.

Weekly and daily schedules must be adhered to as closely as possible. Proper priorities must be placed on new work orders to prevent undue interruption of these schedules.

Scheduler develops a one-week schedule for each crew based on craft hours available, forecast that shows highest skill available, job priorities, and information from the job plans. The one-week schedule assigns work for every available workhour. The schedule allows for emergencies and high priority, reactive jobs by scheduling a significant amount of work on easily interrupted tasks. Preference is given to completing higher priority work by under-utilizing available skill levels over completing lower priority work.

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crew supervisor develops a daily schedule one day in advance using current job progress, the one-week schedule, and new high priority, reactive jobs as a guide.

Wrench time is the primary measure of work force efficiency and of planning and scheduling effectiveness.

Schedule compliance is the measure of adherence to the one week schedule and it effectiveness

208

Scheduling Scope

Bringing together in precise timing the six elements of a successful maintenance job: labor; tools; materials, parts and supplies; information, engineering data and reference drawings custody of the unit being serviced; and the authorizations, permits, and statutory permissions.

Matching next week's demand for service with resources available after accounting for all categories of leave, training, standing meetings, and indirect commitments, plus consideration of individual skills.

Preparation of a "Weekly Schedule" that represents the agreed upon expectation regarding planned work orders to be accomplished with available resources. The schedule also assures that all preventive and predictive routines will be accomplished within established time limits.

Consideration of alternative assignment strategies where the schedule assigns specific jobs to specific people (allowing second-string players into the game to gain experience ... As(feasible).

Ensuring that responsible supervisors receive and understand the planned job packages for scheduled jobs.

209

Work Prioritization

- Critical safety-related items and protective devices — 5
- Critical to continued production of primary product — 4
- Ancillary (support) system t main production process — 3
- Stand-by unit in a critical system — 2
- Other ancillary assets — 1

- Immediate threat to safety of people and plant — 5
- Limiting operations ability to meet its primary goals — 4
- Creating hazardous situations for people or machinery, although not an immediate threat — 3
- Will affect operations after som time, not immediately — 2
- Improve the efficiency of the operation process — 1

Work Prioritization

210

Scheduling with CMMS/Project Tools/ XLS Sheets

- Project Management Tools
- Interaction of Different groups and the sequence and dependencies. Resource requirements, Allocation Resources Loading and resource leveling. AND
- Excel or manual Works Provide Sheet/ Examples
- Scheduling Techniques
- GANTT Bar Chart. This technique shows the time relationship of job tasks in terms of their chronology and simultaneousness.
- Two basic forms; Critical Path Method
- (CPM) or Project Evaluation and Review Technique (PERT). By identifying the "critical path", both these forms depict the shortest elapsed time feasible for completion of major projects. The importance of scheduling in this manner increases as project complexity increases and on-time completion within budget constraints become critical.

211

Managing Work Quality

- Make a common briefing before start of the work the about safety precautions, work precautions and critical activities of the work.
- Follow all the task as per task list, Any task in-applicability or inability must be clarified with Planner/ HOD
- Note down observations and confirm the proof test has been done. Collect values/ photos/ sketches. As required by task document, inspection of critical-work shall be done by designated authority
- Do not hesitate to consult Manual/ Diagram/expert whenever in doubt.
- Maintained general house keeping and work organized, Assemblies , Spares Component must be kept in way not mixed with similar assembly
- The Likely Human error must be kept in mind and shall cross-checked/ supervised for same
- During machine trials function observations must be corelated/ analyze with inspections observation and if required new task can be created.

212

Backlog Jobs/ Work Order Management

- Lead-timework to be done must be identified as far in advance as possible so that the work backlog is known and jobs can be plan effectively and completely prior to scheduling.
- Accurate evaluations should be made of the priority of each job, given the perspective of the overall operation.
- Each job in backlog must be force ranked so that the most important jobs are always scheduled and where possible, executed first.
- Backlogs must be kept within a reasonable range. Backlogs below minimum do not provide a enough volume of work to ensure smooth scheduling and effective utilization of all resources.
- Backlogs above maximum turn so slowly that it is impossible to meet customer needs on a timely basis. Consequently, they loose faith in the proactive approach and slip back into the reactive mode.
- Special or heavy demands resulting in excessive backlog cannot be scheduled unless additional resources are authorized or expected completion dates are relaxed.

213

Effective feedback and Documentation Completion

- All required information as per task list must be submitted in clear terms
- All proof test and final handing over trials values/ Observation shall be provided Care shall be taken to record all observations (as Job progress and shall submitted with Work orders, status / Photographs/ Sketches shall be provided to clarify the observations)
- Any Delay on account of Planning shortcoming, Material availability and similar incident shall be provided. Lesson learned or deviations (Cost, Labor Utilizations, delay diagnostics) if happen shall be highlighted to take care in future work

Operations may fail to release equipment as previously agreed to	FR
Excessive emergencies.	PA
Poor assignment of technicians.	EE
Insufficient technician capacity.	IC
Stock-outs are frequent	SO
Planning packages do not reflect reality. Parts are incorrect, job steps	PP

214

Alignment of Planning and Scheduling processes

- Planning shall be relevant and realistic so can be done efficiently and effectively.
- The planner shall survey the site physically and make task accordingly
- Planner shall accommodate previous relevant feedback and suggestion in work procedure
- Planner shall join scheduling meeting for major works apart from provided detailed task pack.
- maintenance supervisor shall provide all details as per work order closer format and other feedback.
- Maintenance senior craftsman shall assist planner in developing the Maintenance plan, As many craftsman shall be utilized to help planner so in turn they will also learn planning methods
- Planning activities and work feedback requirement must be made clear to all maintenance levels and shall be comply of.
- Planner shall not be involved in day to day maintenance operation and always planned for next week
- Planning and Scheduler must analyze maintenance delivery performance and work out to improve the same.

Planning and Scheduling Matrices

- Percentage of planned work. This measure is the percentage of all scheduled jobs that have been planned. It assumes that all parts, procedures, specifications; tools, drawings, etc., have been identified before the job is scheduled. The benchmark is 90%.
- Percentage of schedule compliance. This measure is the percentage of work accomplished that is agreed upon or on the weekly schedule.
- **Percentage of time that kits (materials and parts) are delivered on time**. This measure is calculated as the number of times the kits (material and parts) were delivered on time divided by the total number of kits delivered. This percentage affects the planner's ability to plan jobs properly. Expediting parts adds unnecessary and wasteful cost to the P&S process.
- **Percentage of time the right part (s) is delivered**. As part of the planning process, planners and schedulers should have the confidence that a specific vendor will deliver the right part when required. Otherwise this problem could create a delay in performing the work. The benchmark is 99.0% or higher.
- Percentage of work from a formal work PM/CBM. Most work should come from identifying the degradation of a component or asset far enough in advance of any PM/CBM tasks that the job can be planned and scheduled properly, thus minimizing unexpected delays and production loss.
- Percent Rework. This measure is the percent of work orders requiring rework. Each organization needs to define what rework means to them. It may differ from one to another organization. The benchmark number is less than 2%.

216

Key Performance Indicator

- Availability Hrs (Equipment wise+ line wise)
- Availability % (Equipment wise+ line wise)
- MTBF (Equipment wise+ line wise)
- MTTR (Equipment wise+ line wise)
- Reliability Prediction based on failure rate (Equipment or Line wise)
- Fault code wise line Up (Equipment wise, Section wise)
- Remedy code wise line-up (Equipment wise, Section wise)
- Total Cost work Order wise (include Man-hour and Material Cost)
- Total Cost Equipment wise(for a given period)
- Total Cost for selected Equipment (for a given period)
- Material Cost work Order wise (include Man-hour and Material Cost)
- Material Cost Equipment wise(for a given period)
- Material Cost for selected Equipment (for a given period)

217

Key Performance Indicator

- Manpower Cost work Order wise (include Man-hour and Material Cost)
- Manpower Cost Equipment wise(for a given period)
- Manpower Cost for selected Equipment (for a given period)
- How many corrective Oder generated vs Corrective order Closed (for a Given period)
- How many CAPA order generated against CAPA orders Closed.
- Productivity Total Hrs. work done/Total hr. Availability.
- BD hrs % Against Total hr.
- Corrective hr % Against hr.
- Preventive Hr % AGAINST Total hr Available
- Craftsman Competency Quotation (Ratio of Avl/ desire)
- Due Calibrations
- Critical Spares reorder level
- Energy Monitoring for Plant Equipment

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Q & A SESSION

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