GLOMACS

International Partners with Oxford Management

OXFORD MANAGEMENT CENTRE

Optimising Equipment Maintenance & Replacement Decisions

20 - 24 October 2014

Carlton Conference Centre, Kuala Lumpur

By

Mr. Max Zornada

Senior Consultant

Participant's Name	

Optimizing Equipment Maintenance and Replacement Decisions

Program Content Topic Overview by Day

Topics

Day 1	**Physical Asset Management and Reliability Concepts** 1. Introduction to the Maintenance Management Process 2. The Path to World Class Maintenance 3. Maintenance Self-Assessment 4. Maintenance Best Practice Benchmarks Review
Day 2	**Reliability and Preventive Maintenance Strategy** 5. Foundations of Reliability 6. Measuring Maintenance Performance 7. Reliability Based Preventive Maintenance Strategy 8. Preventive Maintenance Optimisation 9. Spare Parts Strategy 10. Risk Based Maintenance
Day 3	**Condition Monitoring and Statistical Methods** 11. Condition Monitoring and Predictive Maintenance 12. Introduction to Statistical Methods in Maintenance 13. Failure Analysis 14. Using Statistical Methods to Determine Optimum Maintenance Strategies
Day 4	**Economics of Reliability** 15. Capital Decision Making in Maintenance 16. Discounted Cash Flow Analysis 17. Life-Cycle Cost Concepts 18. Repair vs Replace Decisions
Day 5	**Effective Management of Maintenance Resources and Information** 19. Organisational Level Maintenance Strategies 20. The Availability-Reliability Matrix 21. Outsourcing and Use of Contractors 22. Computerised Maintenance Management Systems

Detailed Table of Contents

Module 3: Condition Monitoring and Statistical Methods in Maintenance

To be handed out as a standalone handout during sessions.

Module 4: Economics of Reliability

Module 5: Effective Management of Maintenance Resources and Information

Module 6: Computerised Maintenance Management Systems

Presenter Profile

Mr. Max Zornada B.E. (Mech), Hons. M.B.A.

Max is a Senior Consultant with Glomacs, a Management Educator with extensive experience teaching MBA, Executive Education and Management Development Seminars and as a hands-on practitioner, consulting to major corporations on a range of Operational and Strategic issues, throughout Australia, the US, Middle East, UK, Western Europe and Asia.

Max Zornada is an Adjunct Lecturer at the University of Adelaide Business School where he currently teaches the Operations Management and Business Improvement in the MBA Program. He has also taught Project Management, Managing Innovation and Technology and E-Business.

He delivers various Executive Education Programs including Yellow Belt, Green Belt and Black Belt level Lean Six Sigma programs.

He has also presented programs for the University of New South Wales, Southern Cross and was a Visiting Professor at the Consorzio MIP at the Politecnico di Milano.

Max spent several years with the London based international management and technology consultancy PA Consulting Group, after holding various managerial and professional engineering positions in the chemicals processing and petrochemicals industry with Adelaide and Wallaroo Fertilisers, ICI and Santos.

During his time working in the Petrochemical Industry, Max developed specific expertise in Maintenance Management, Shutdown and Turnaround Management, Process Plant Start-up and Commissioning through hands-on involvement in commissioning of new plant, as a Shutdown/Turnaround Manager and implementing computerised maintenance management systems.

He has used this experience to develop a range of training programs on topics such as Process Plant Start-up and Commissioning, Shutdown and Turnaround Management, Maintenance Management which he runs in locations around the world such as Dubai, Abu Dhabi, Kuwait and Bahrain as public programs and on an inhouse basis.

From his base in Adelaide, Australia, Max maintains an active international consulting and education practice, with a focus on the management of capital intensive (petrochemical, energy and chemicals) businesses in the Middle East, Europe and Asia.

Introduction

- Is your equipment (fixed or mobile) failing before planned replacement?
- Are you unable to execute maintenance tasks because spare parts are not available?
- Have you made significant investment in CBM methods and tools but struggle to realize the benefit?
- Do you have lots of data from oil analyses but still struggling to accurately predict your equipment breakdowns?
- Do you know how to determine optimum asset life?
- Are you struggling to justify the economics of asset replacement?
- Are you having difficulties in deciding whether to rebuild or replace your equipment to minimize the life cycle costs?
- Do you need to optimize your emergency spare requirements?

Objectives

The objectives of the program can be summarized as follows:

- To focus on the techniques of optimization - the single most important thrust of this learning program. Whether the decision is about work-crew sizes, or the replacement of component-parts or entire equipment units, the concept of making the very best, most optimal, decision will be the principal concern of the training program.
- The concept of making the very best, most optimal, decision will be the principal concern of the training program.
- To equip the participating maintenance managers, planners and schedulers and engineers with the know-how to select the most appropriate analytical tools for their maintenance decision-making.
- Reflecting the growing focus of industrial safety and the profusion of safety-related litigation - think of transportation accidents, chemical spills, and mining disasters - the program will show how safety objectives relate to the optimization models, and will underline the advantages of having a well-documented and rigorously-executed program of maintenance and replacement.
- To introduce the critical decision-making topics that can make a significant difference to the in-service time of equipment, to the costs related to doing maintenance too often or too seldom, and the optimization of asset utilization.
- To not only cover the classic need-to-know material in the area, but to acquaint the participants with leading-edge and on-the-horizon approaches that they will encounter in the near future.

Training Methodology

The course will combine presentations with interactive practical exercises, supported by numerous case studies. Delegates will be encouraged to participate actively in relating the methodologies and tool s presented during the 5-day course to the particular needs of their workplace.

Organisational Impact

Focus on the most advanced techniques for Maintenance Optimization:

- Select the most appropriate Analytical tools for maintenance decision making
- Relate Safety objectives to optimization models
- Introduce Critical Decision-Making Topics
- Acquaint with Leading-Edge and On-The-Horizon approaches
- Continue to Apply the Course-Learning to your workplace problems

Personal Impact

- Equipment maintenance and replacement decision are frequently based on informed opinions or subjective responses to common situations. In this course, we will deal with procedures based on careful research that is firmly rooted in reality. The course is intended to give you the tools needed to make data-driven decisions, which you can apply in your own environment and upon which you can rely to help you in developing appropriate programs. With so much data available, we often find ourselves in the bewildering position of being data – rich but information poor. We may have all the raw data we'll ever need at our fingertips; but unless we can interpret and integrate it properly, it is of little use. To refine this data into useful information, we need the appropriate tools.
- This course is designed to give you those tools. Our time is limited, and our individual interests and concerns vary. So we may not solve your particular problems in this course. However, I hope it will at least provide you with the concepts and techniques you need to address problems that arise as you carry out your responsibilities.

Who Should Attend?

- Engineers
- Professionals of Plant operations
- Facility Professionals
- Maintenance or Reliability professionals who are responsible for maintaining and managing the physical equipment assets of a Plant/Facility

The ideal candidate for this seminar is an Engineer, Professional of Plant operations, Facility Professional, Maintenance or Reliability professional who is responsible for maintaining and managing the physical equipment assets of a Plant/Facility. He or she represents large Facilities and Plants from industries such as Oil and Gas, Petrochemical and Fertilizer, Pulp and Paper, Cement and Ceramics, Power Generation and Utilities, Primary Metals, and Heavy Manufacturing and Facilities.

SEMINAR OUTLINE

DAY 1: Physical Asset Management & Reliability Concepts

From Maintenance Management to Physical Asset Management

- Challenges of physical asset management
- The maintenance excellence pyramid
- Total Productive Maintenance
- Reliability Centered Maintenance
- Optimizing Maintenance & Replacement Decisions

Reliability Improvement through Preventive Maintenance

- Analysis of Component Failure Data
- Probability Density Function
- Reliability Function
- Weibull Density
- Infant Mortality
- Bath-Tub Curve

Exercise in Analysing Component Failure Data Using the Weibull Distribution

- Estimating the Weibull Parameters
- Using Median Rank Tables

Dealing with Censored Data, the 3-Parameter Weibull, and the Kolomorgov-Smirnov Test

- Upper-End Censoring, Multiply Censored Group Data
- Estimating the Location Parameter in the Weibull Distribution
- Checking the Goodness-of-Fit of the Distribution

DAY 2 Preventive Maintenance & Spare Parts Replacements

Reliability Improvement through Preventive Maintenance (continued)

- Component Replacement Procedures including Glasser's Graph
- Block Replacement Policies
- Age-Based Replacement Policy
- Setting Policies based on Safety Constraints, Cost-Minimization and Availability-Maximization
- Repairable systems

Case Studies in Component Preventive Replacement

- Including boiler plant, bearings, pumps, sugar feeds, compressor valves, and centrifuges

Spare parts provisioning

- Fast moving spares
- Emergency (insurance) spares

Case studies in spares provisioning

- Including line replaceable units (LRUs), cylinder heads, repairable conveyor electric motors and utility transformers

Group and individual exercises

Clinic: Hands-On Use of PC Software (OREST) for Preventive Replacement Strategies

- Participants will solve pre-set problems

DAY 3 Machine Health Monitoring & Inspection

Reliability Improvement through Inspection

Inspection Frequency and Depth for equipment in continuous operation

- Inspection Intervals to Maximize Profit
- Maximizing Equipment Availability
- Inspection Intervals for Equipment Used in Emergency Situations (e.g. protective devices)
- Case studies including oil and gas field equipment such as pressure safely valves (for protective devices)

Health-Monitoring Procedures

- Proportional Hazards Modelling
- Spectroscopic Oil Analysis Programs
- Optimization of Condition-Based Maintenance Procedures
- Role of EXAKT software for CBM optimization
- Case studies including food procession industry (vibration monitoring), pulp and paper and shipping equipment such as compressors (vibration monitoring) and diesel engines (oil analysis), turbines in an electrical generating station (pressure measurements)

DAY 4 Economics of Reliability

Reliability Improvement through Asset Replacement

Aspects of Discounted Cash Flow Used in Capital Equipment Replacement Analysis

- Estimating the Interest Rate Appropriate for discounting
- Present-Value Calculations
- The effects of Inflation in the Analysis
- Calculating the Equivalent Annual Cost (EAC)

Economic Life of Capital Equipment

- The "Classic" Economic Life Model
- Before-and-After Tax Calculations
- The Repair-vs-Replace Decision
- Life-Cycle Costing
- Technological Improvement

Group and individual exercises

Clinic: Hands-On Use of PC Software (AGE/CON and PERDEC) for Capital Equipment Replacement Analysis

- Participants will solve pre-set problems

DAY 5 Effective Management of Maintenance Resources & Information

Effective Use of Maintenance Resources

Organizational Structure, Crew Sizes, Workshop Resource Requirements

- Balancing Maintenance Costs against Plant Reliability
- Establishing the optimal number of machines to have in a workshop
- Resource Requirements Using Queuing Theory and Simulation

- Utilization of Outside Resources
- Lease-vs.-Buy Decision

Case studies including balancing maintenance cost and reliability in an electrical generating station, establishing optimal mix of machines to have in a steel mill maintenance workshop, establishing shift patterns and maintenance crew sizes in a petrochemical plant.

Maintenance Management Information Systems

- Methodology for Auditing a CMMS

Discussion Period for Left-Over Questions
Summary of Issues Covered, Lessons Learned

Module 1:

Physical Asset Management and Reliability Concepts

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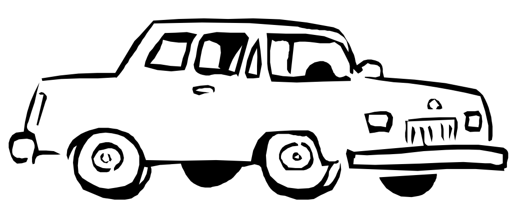
The Management Process
Case Study

Smith's Auto-Service Centre



Smith's Auto-Service Centre

After some 15 years working as a mechanic in the after sales service division of a major dealership, Bob Smith decided to go into business for himself. He and his brother Phil, pooled their savings and managed to secure a loan from their bank, to buy an auto-service centre located in the central business district.

Smith's Auto-Service Centre employed 5 mechanics and 1 auto-electrician. It consisted of 8 service bays, a small workshop facility for refurbishing major items and an electrical work area.

Bob was the overall "business manager" while his brother Phil looked after some of the support functions such as sourcing and purchasing spare parts, "drumming up" business from some of the local businesses and offering specialist services to local garages.

Typically, the Smith's main sources of business came from:

- Customers who lived/worked locally booking in their cars for a routine service or tune-up. These customers were keen to get their cars back the same day. Typically they would drop off their cars in the morning and expect them to be ready by the afternoon. Many of these customers included local business who had agreed to have all of their company cars serviced by Smith's Auto Service Centre. Bob's usual practice was to book these in approximately a week in advance.
- Customers who lived/worked locally bringing in their cars to have some kind of problem investigated and repaired. Bob tried to book these types of jobs in to be done within a week of the customer first coming in with the problem.
- Local garages sub-contracting specialist work to the Smith's eg. Electrical work and work requiring machining facilities (which the Smith's had). Bob had asked the local garages for at least a week's notice for this type of work, but quite often they would only find out about these jobs on the same day that they were required. In such cases, unless they had some slack, Bob usually slotted these jobs in for the next day.
- Customers coming in off the street with some urgent problem needing immediate attention.

Bob felt that the local customers who lived and or worked in the area, and booked their cars in for services or other work were the most important. It was from these that he was most likely to get the volume of repeat and on-going business that he required to make his business viable in the long-term.

The Smith's first few months had been close to a disaster. Many of the local customers had been dissatisfied and there had been many complaints, as their cars had not been ready within the day as promised.

Bob's practice had been to book in at least 4 cars per mechanic per day, in this way leaving some time free to attend to any urgent work that arose during the day.

Although some days worked out well, other days had been an absolute disaster.

The following events were typical of the kind of things that happened:

- Sometimes, cars required major work or significantly more than a routine grease and oil change taking almost the full day to be completed. In such cases, 2 or 3 of the cars allocated to each mechanic were left unserviced. Bob often did not find out about these until just after the afternoon tea break by which time it was too late to reallocate other mechanics to help with these jobs;
- Bob did not carry stocks of oil filters and other components for some of the more exotic cars and time was often wasted chasing these up. Similarly, some of the repairs where often delayed when they required parts that were not carried in stock;
- Service and repair work was often left, to attend to customers who came in off the street in a panic with some problem needing immediate attention. Many of these problems were fixed relatively quickly. However, on some mornings, particularly when it was raining, there was a rush of these types of jobs. It was not unusual for 2 or 3 mechanics to get "tied up" until lunchtime doing this type of work, before they were free to get onto the service work. In addition, the occasional problem car came in which could take one or more days to fix.

- Bob wondered what he could do to deal with some of the problems he was experiencing, in particular those that were affecting his regular service and repair work customers.

Questions

Discuss some of the problems Bob is experiencing.

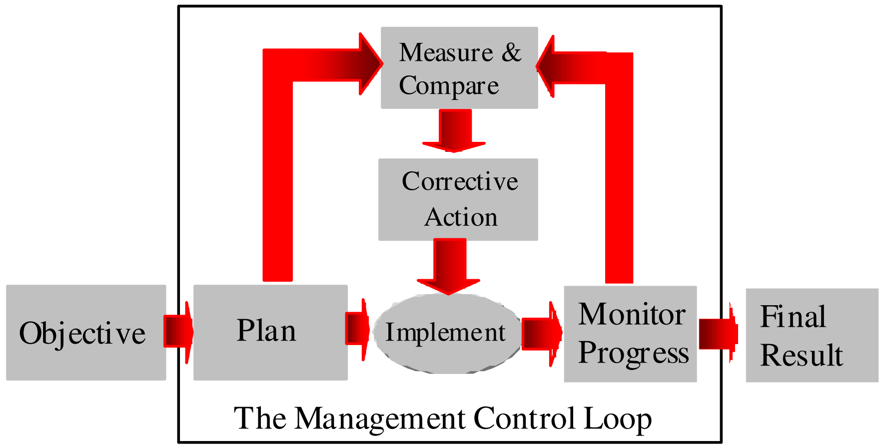
What are some of the things that Bob could do to improve things and make his operation run more smoothly. In particular, consider:

- How can Bob improve the level of customer satisfaction for what he regards as his most important customer group?
- How can he get a better match between the work coming in, the services and repairs that are prebooked in particular, and the labour he has available so that the cars that have been slotted in for a particular day actually get done that day?
- What can he do to avoid delays due to parts not being available?
- How can he better find out when some-one is running behind with their day's work so as to reallocate people working on less important work before it is too late?

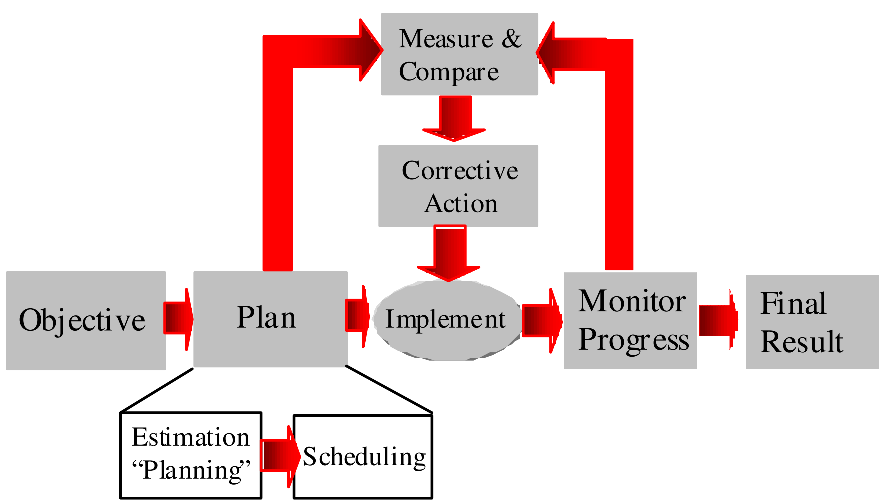
Notes

The Management Process

OPIC - Objectives, Plans, Implementation, Control.



The "Plan" Stage



The key management activities

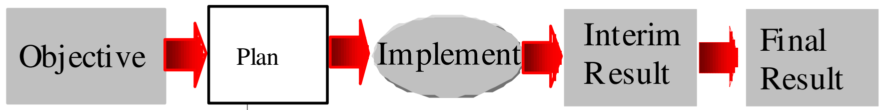
- Setting Objectives
- Developing plans and schedules
- Implementing - allocating tasks
- Measuring and monitoring results
- Taking corrective actions

Optimising Equipment Maintenance

The Management Process in Maintenance

- Work receipt for corrective maintenance
- Authorisation of incoming work
- Preventive maintenance plan work
- Approach to Prioritisation;
- Total work that needs to be done to meet production reliability and availability requirements;
- Degree of responsiveness.

The Management Process in Maintenance



Work Estimation

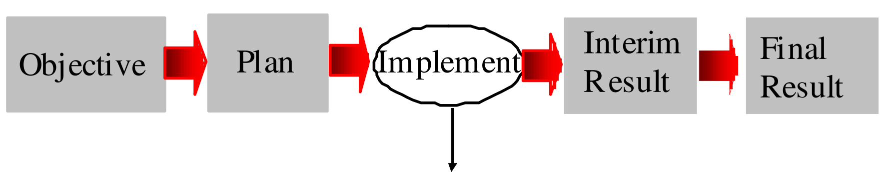
- Understanding the work requirement;
- Determining the required tasks and job method;
- Estimating labour requirements by trade/skill
- Estimating materials
- Estimating other requirements
  – Cranes, transport, etc.

Work Plan *(outcome)*

Scheduling

- Determining when work should be done;
- Allocating work to people - who will do it.

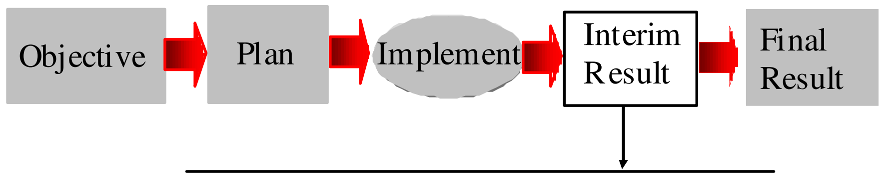
The Management Process in Maintenance



- Issue work to maintenance person
- Issue materials and other requirments
- Make plant equipment available
- Execute the work package
- Work to the plan according to the schedule.

Optimising Equipment Maintenance

The Management Process in Maintenance



- Supervision!
- Checks of progress of key jobs;
- Checks of progress during the day against the daily schedule
- Checks of progress at end of each day against weekly schedule.

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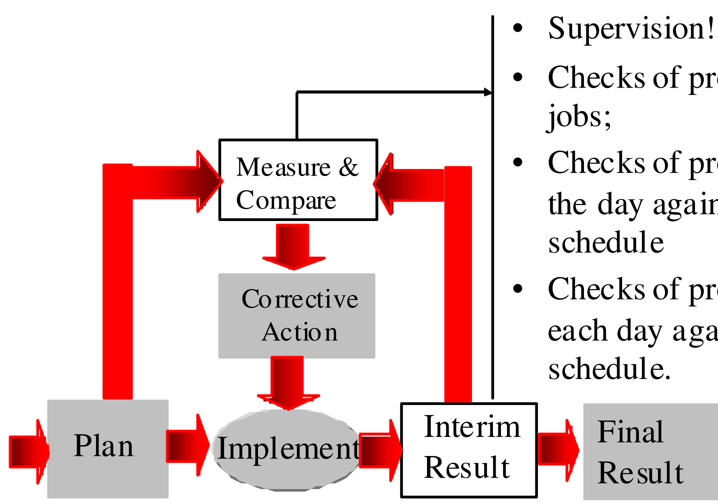
Optimising Equipment Maintenance

The Management Process in Maintenance



- Supervision!
- Checks of progress of key jobs;
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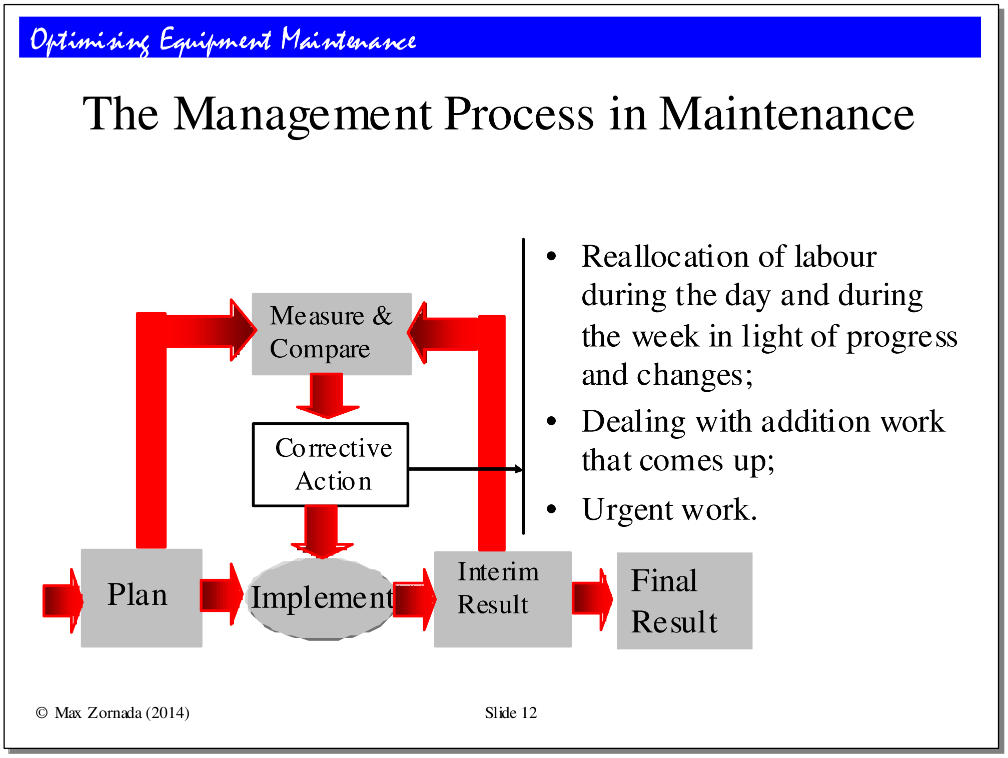
Optimising Equipment Maintenance
The Management Process in Maintenance
Measure & Compare
Corrective Action
Plan
Implement
Interim Result
Final Result
• Reallocation of labour during the day and during the week in light of progress and changes;
• Dealing with addition work that comes up;
• Urgent work.
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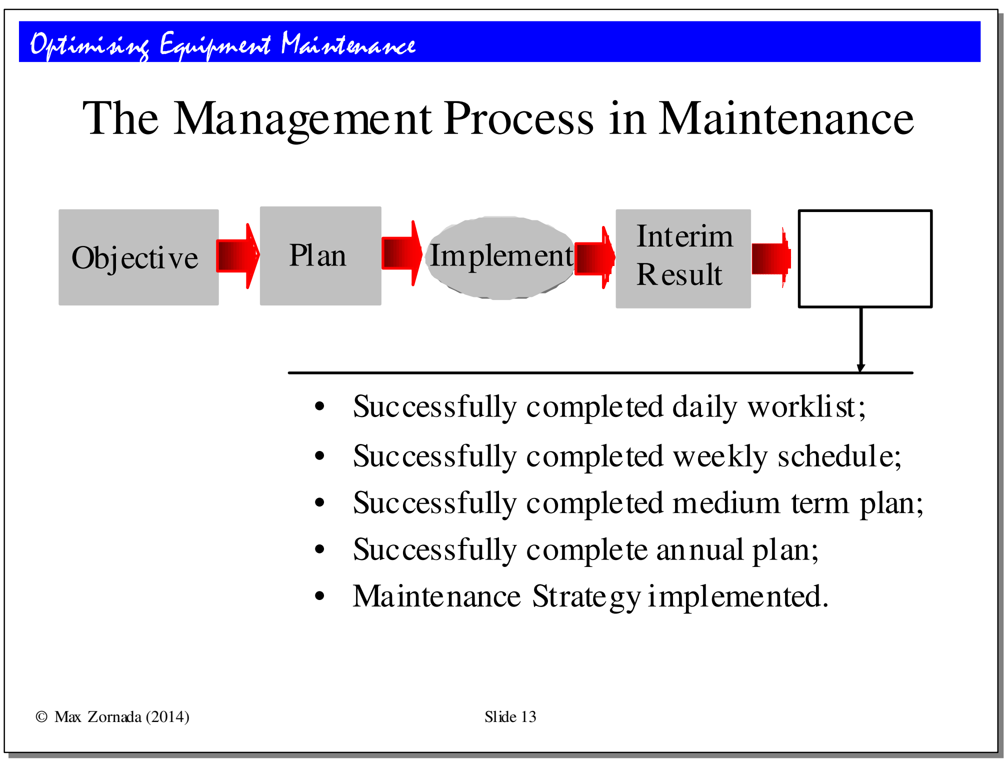
Slide 12


Optimising Equipment Maintenance
The Management Process in Maintenance
Objective
Plan
Implement
Interim Result
• Successfully completed daily worklist;
• Successfully completed weekly schedule;
• Successfully completed medium term plan;
• Successfully complete annual plan;
• Maintenance Strategy implemented.
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Maintenance Management

- Maintenance Management is about applying "management" processes to maintenance;
- "Management" processes are applied by way of a "system" that establishes a set of management practices with associated information requirements required to make the system work;
- Computer systems often support the information requirements - but most of what makes an effective maintenance management system is done by people.

Definitions: Types of Maintenance Work

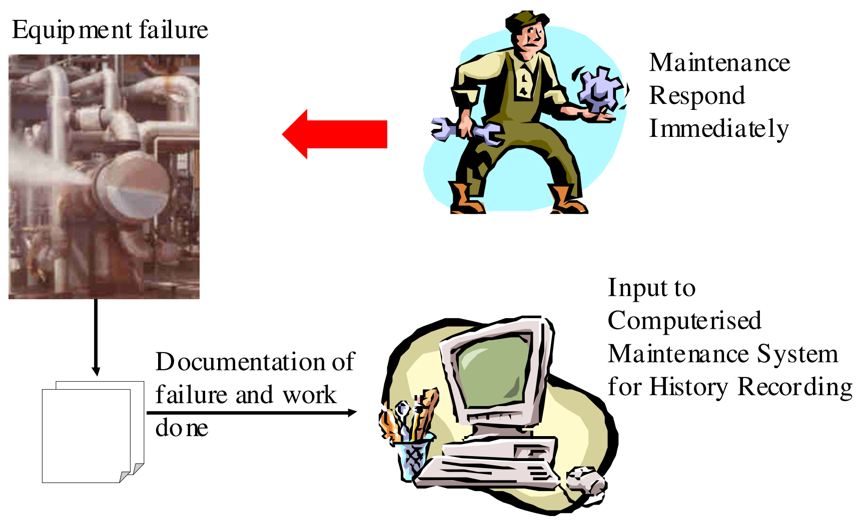
- Reactive Maintenance:
  - Urgent work that needs to be done immediately, such that there is no time to plan in advance. Usually in response to a breakdown or failure having immediate impact on operations. Can be also referred to as <u>breakdown maintenance, unplanned corrective, emergency or urgent work</u> and will therefore be unplanned.
- Corrective Maintenance:
  - Work done in response to the identification of a defect or abnormal operating condition, which if unattended would result in a breakdown/failure. The fact that failure has not occurred yet offers the opportunity to plan and coordinate the execution of this work in advance. This type of work is often referred to as <u>planned repairs, planned corrective or proactive maintenance.</u>
- Preventive Maintenance:
  - Any work done as a deliberate attempt to pre-empt a failure or the development of a defect which is initiated proactively. (<u>Is not done as a response to a breakdown or identified defect</u>.). This includes Predictive Maintenance.

Note: Corrective Maintenance that has been planned in advance and Preventive Maintenance, together are often referred to a planned maintenance.

Maintenance Timing

- Operating or running maintenance:
  - Maintenance work (of any type) done and/or scheduled to be done in a way that does not interrupt normal operations.
- Shutdown/Turnaround Maintenance:
  - Maintenance work (of any type) that can only be done when the plant is shutdown.

Reactive Maintenance



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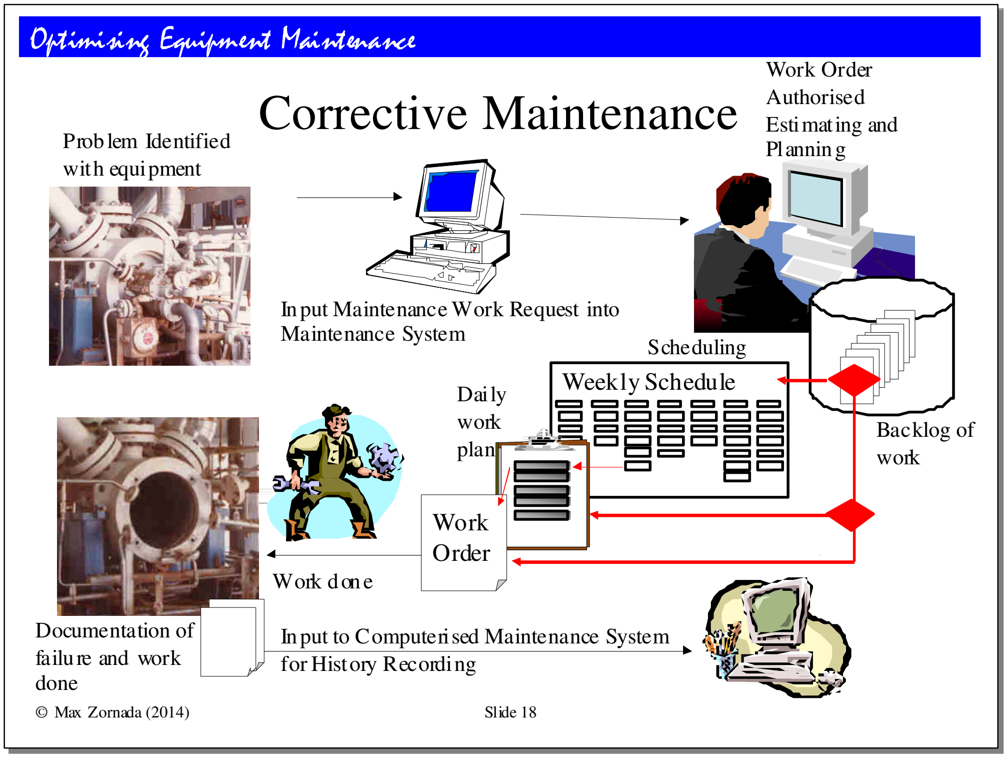
Optimising Equipment Maintenance
Corrective Maintenance
Problem Identified with equipment
Input Maintenance Work Request into Maintenance System
Work Order Authorised Estimating and Planning
Scheduling
Weekly Schedule
Backlog of work
Daily work plan
Work Order
Work done
Documentation of failure and work done
Input to Computerised Maintenance System for History Recording
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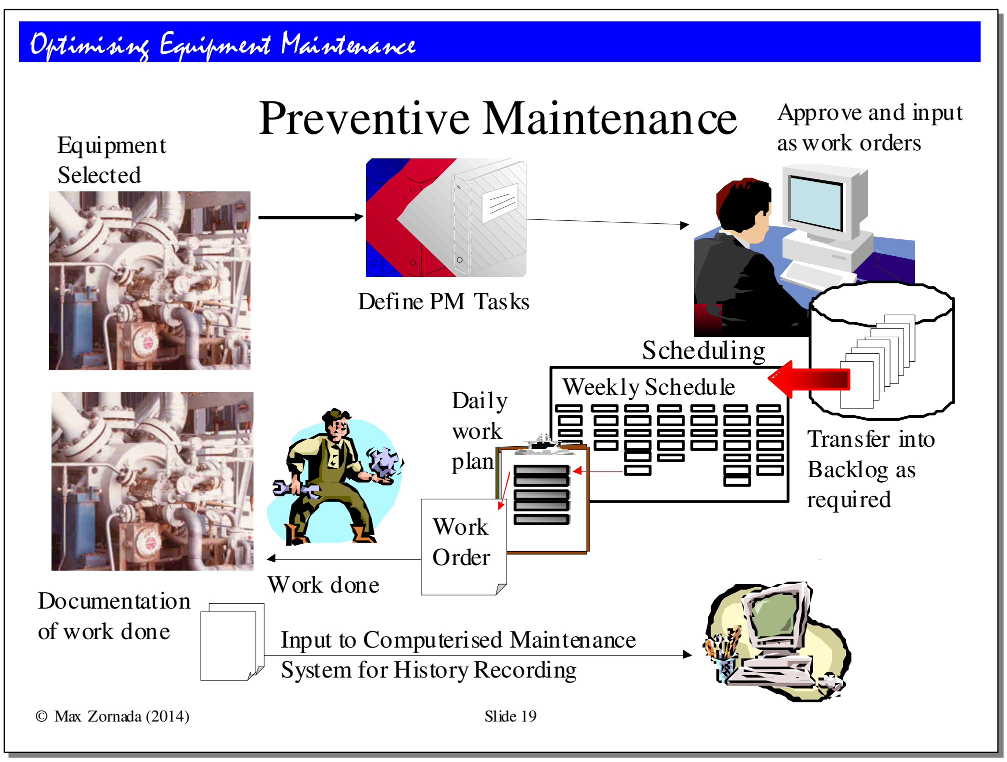
Optimising Equipment Maintenance
Preventive Maintenance
Equipment Selected
Define PM Tasks
Approve and input as work orders
Scheduling
Weekly Schedule
Transfer into Backlog as required
Daily work plan
Work Order
Work done
Documentation of work done
Input to Computerised Maintenance System for History Recording
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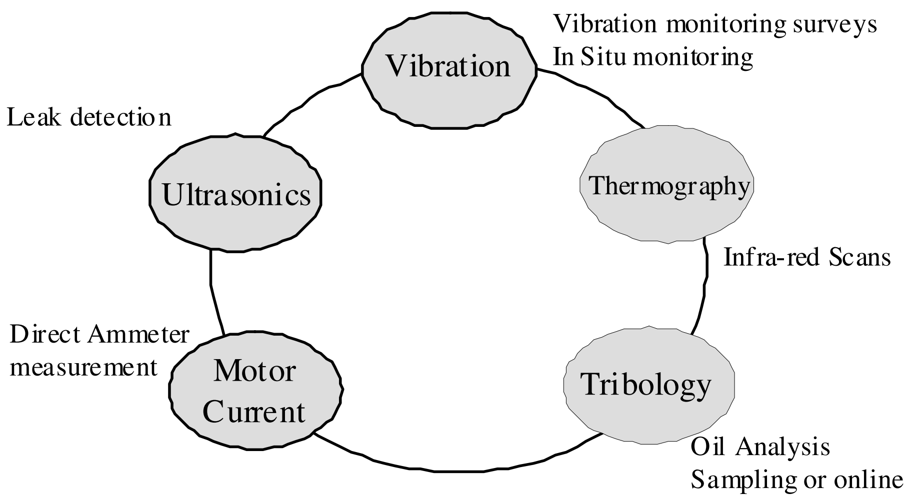
Types of Preventive Maintenance

- Fixed time or Fixed interval inspections, component replacement or refurbishment/overhaul;
- On condition based inspections, component replacement or refurbishment/overhaul;
  - Run hours based;
  - Indicator based;
  - Predictive Maintenance Techniques.

Optimising Equipment Maintenance

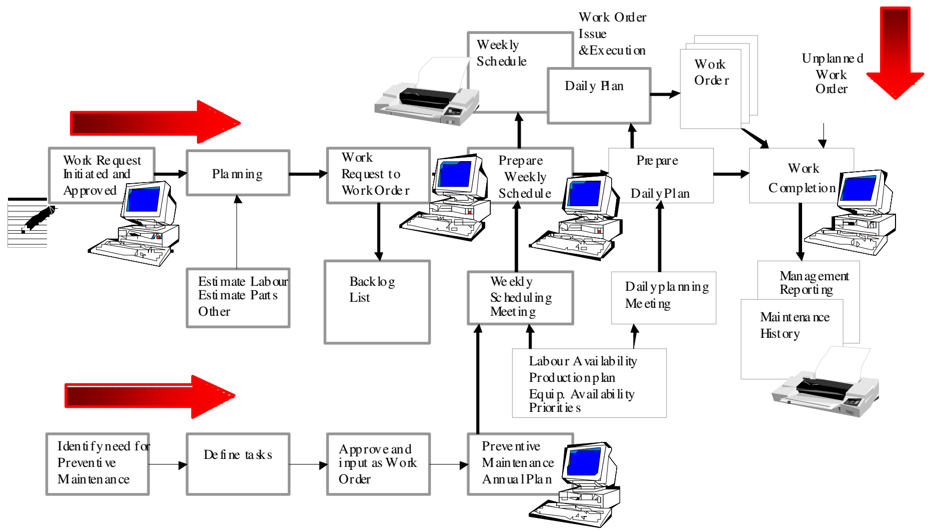
Predictive Maintenance

Common Techniques



Optimising Equipment Maintenance

Maintenance Management System Work Flows



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Optimising Equipment Maintenance

Approaches to Improvement

Organisations have at various times tried many approaches to improvement

- Preventive Maintenance;
- Computerised Maintenance Management Systems;
- A focus on planning and scheduling work;
- Total Productive Maintenance;
- Self-directed work teams;
- Predictive Maintenance & Condition Monitoring;
- Reliability Centred Maintenance (RCM)and Preventive Maintenance Optimisation (PMO);
- Predictive Maintenance;
- Risk Based Maintenance.

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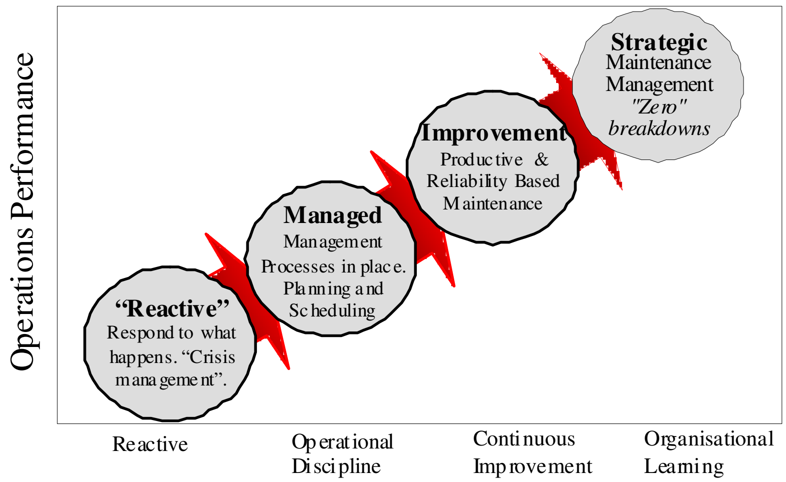
Optimising Equipment Maintenance

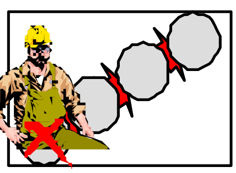
The Path to World Class Maintenance

Key Vision Milestones



Slide 1

Optimising Equipment Maintenance



Reactive Maintenance Management

Key Features

- ☐ React to breakdowns and other problems as they occur;
- ☐ Try to keep up with the work as it comes in;
- ☐ Maintenance find out about problems as they arise;
- ☐ Only jobs not done as they come up are those that cannot be done either through lack of access or lack of parts;
- ☐ Maintenance Managers and Supervisors are unaware of Backlog. It is "invisible" or in different people's heads;
- ☐ Backlog is not acknowledged or measured.
- ✓ *Do any of these apply to your organisation?*

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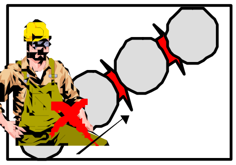
Optimising Equipment Maintenance



Preventive Maintenance

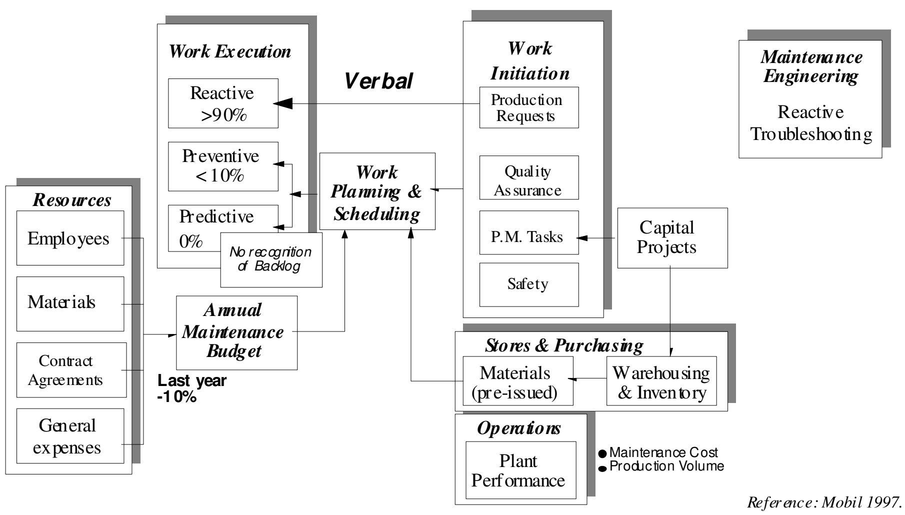
The First Step on the Improvement Process

- "Planned" Preventive Maintenance, usually on fixed time or fixed interval basis is scheduled to be done, so as to reduce the number of breakdowns;.
- Remainder of work (majority) is done the same as for reactive maintenance management.

Slide 3

Optimising Equipment Maintenance

Maintenance Process Map - Many Organisations



Reference: Mobil 1997.

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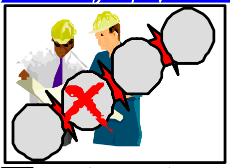


"Managed" Approach to Maintenance

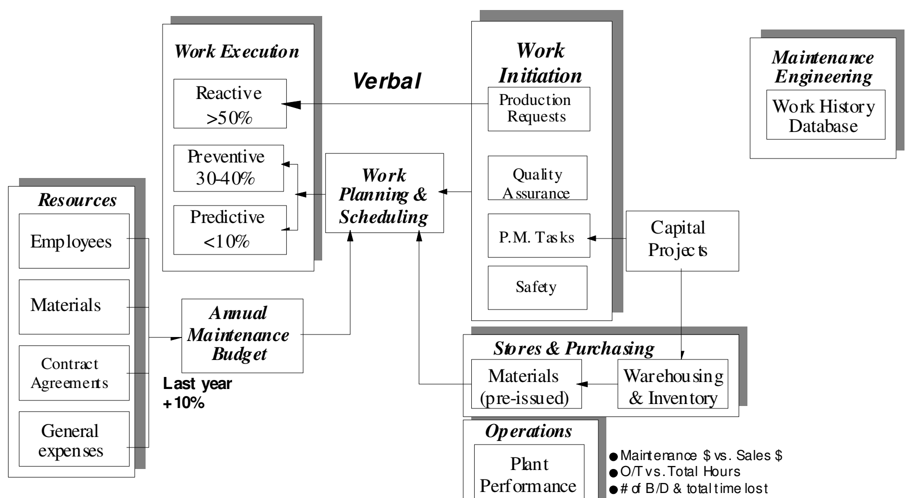
Key Features

- ☐ Planned preventive maintenance is scheduled to be done on a regular basis. This may include predictive maintenance inspections and condition monitoring;
- ☐ "Urgent" breakdowns are reacted to when they occur;
- ☐ An effective priority/criticality system is in place that clearly identify genuinely urgent work from planable work.
- ☐ All other work is planned and registered on a "backlog" as soon as it is known about;
- ☐ Work is scheduled from the backlog on a weekly basis;
- ☐ Backlog levels are known, monitored and managed.

✓ *How many of these apply to your organisation?*

Optimising Equipment Maintenance

Typical Maintenance Process Map (Average Performance)



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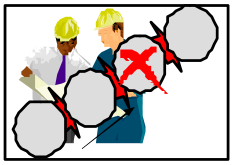


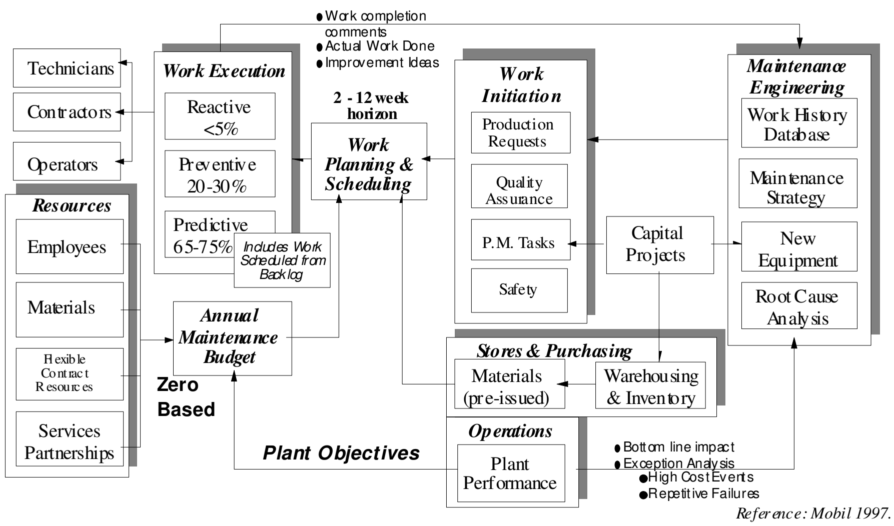
Increasing Level of Performance through Improvement Strategies

Key Features

- ☐ Use of Reliability Centred Maintenance and Preventive Maintenance Optimisation to improve effectiveness of Preventive Maintenance
- ☐ Increasing levels of planned and scheduled work
- ☐ Maintenance of Backlog at target levels
- ☐ Improvement in equipment and plant reliability through problems solving and root cause analysis techniques
- ☐ Streamlining of spare parts management and matching to maintenance strategy.

✓ *How many of these apply to your organisation?*

Best Practice Maintenance Process Map

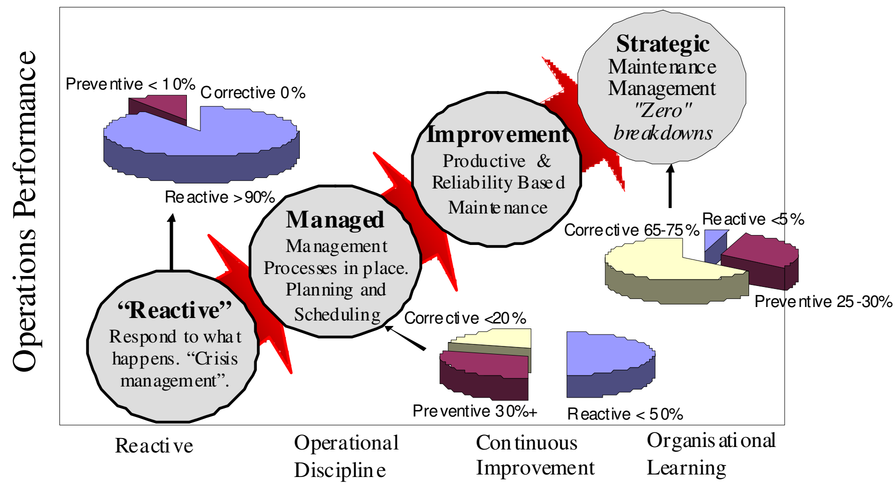


Reference: Mobil 1997.

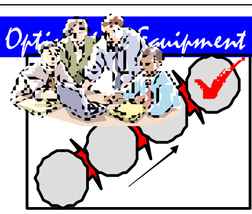
GLOMACS International Partners with Oxford Management
OXFORD MANAGEMENT CENTRE

The Path to World Class Maintenance

Key Vision Milestones



Optimising Equipment Maintenance



The Goal - "Zero Breakdowns"

Key Features

- ☐ Combination of backlog management practices, preventive & predictive maintenance has eliminated almost all reactive maintenance;
- ☐ Preventive and predictive maintenance tasks are determined by a reliability based maintenance strategy;
- ☐ Breakdowns are only allowed to happen when this has been selected as the best strategy;
- ☐ The majority of maintenance work is as a result of predictive/ preventive routines and/or from the backlog. It is actioned through the weekly schedule;
- ☐ Spare parts logistics support is aligned to the maintenance strategy.
- ✓ *How many of these apply to your organisation?*

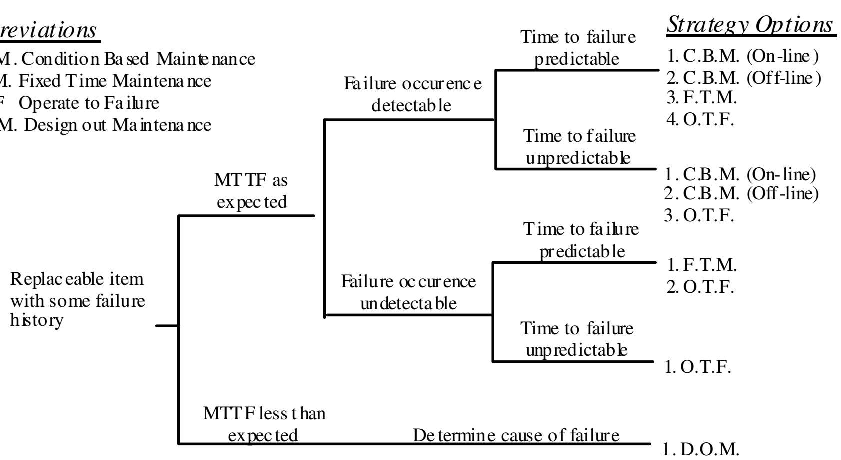
Optimising Equipment Maintenance

Equipment and Component Failure Characteristics

Determining the Optimum Maintenance Strategy

Abbreviations

C.B.M. Condition Based Maintenance
F.T.M. Fixed Time Maintenance
O.T.F Operate to Failure
D.O.M. Design out Maintenance



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Optimising Equipment Maintenance

Reliability Based Maintenance Strategy Chart

	Criticality 1					
	Total product lost irretrievably Major Safety/Environmental Impact					
Differential Maintenance Cost of Failure	High (>$3,000)			Low (<$3,000)		
Failure Predictable	Yes	No		Yes		No
Type of Maintenance						
Inspection/Lubrication	Y	Y		Y		Y
Preventive Maintenance (Task)	Y	Y		Y		Y
Condition Monitoring	Y	N		Y		N
Change Out On Life	N	Y		N		Y
Run to Failure	N	N		N		N
Investigation of Breakdowns	Y	Y		Y		Y
Off-Site Repairs (Assuming can be done on site)						
Use Rotable						
Value of Rotable Stock	>$100K		$20-100K		<$20K	
Repair Time < 1 Day	Y		Y		Y	
1-3 Days	Y		Y		Y	
3-15 Days	Y		Y		Y	
>15 Days	Y		Y		Y	
Stock Holdings (Items< $20,000) (Whether to Hold Stock or Not)	Assumes no Rotable Stock held for the part					
Value of Total Stock Holding	$2,000 - -$20,000		$500- -$2,000		<$500	
Failure Predictable?	Yes	No	Yes	No	Yes	No
Lead Time						
< 1 Day (Avail Ex. Stock-Local)	Y	Y	Y	Y	Y	Y
1-5 Days (Avail Ex. Stock-Country)	Y	Y	Y	Y	Y	Y
5-15 Days	Y	Y	Y	Y	Y	Y
>15 Days	Y	Y	Y	Y	Y	Y

	Criticality 2					
	Partial Production loss or loss of efficiency. Major Environmental Impact					
Differential Maintenance Cost of Failure	High (>$3,000)			Low (<$3,000)		
Failure Predictable	Yes	No		Yes		No
Type of Maintenance						
Inspection/Lubrication	Y	Y		Y		Y
Preventive Maintenance (Task)	Y	Y		Y		Y
Condition Monitoring	Y	N		Y		N
Change Out On Life	N	Y		N		N
Run to Failure	N	N		N		Y
Investigation of Breakdowns	Y	Y		Y		Y
Off-Site Repairs (Assuming can be done on site)	To be decided individually					
Use Rotable						
Value of Rotable Stock	>$100K		$20-100K		<$20K	
Repair Time < 1 Day	N		N		N	
1-3 Days	N		N		Y	
3-15 Days	Y		Y		Y	
>15 Days	Y		Y		Y	
Stock Holdings (Items< $20,000) (Whether to Hold Stock or Not)						
Value of Total Stock Holding	$2,000 - -$20,000		$500- -$2,000		<$500	
Failure Predictable?	Yes	No	Yes	No	Yes	No
Lead Time						
< 1 Day (Avail Ex. Stock-Local)	N	Y	N	Y	Y	Y
1-5 Days (Avail Ex. Stock-Country)	N	Y	Y	Y	Y	Y
5-15 Days	Y	Y	Y	Y	Y	Y
>15 Days	Y	Y	Y	Y	Y	Y

	Criticality 3					
	Increased risk of production or efficiency loss. (Spared equip, by pass control valves etc.)					
Differential Maintenance Cost of Failure	High (>$3,000)			Low (<$3,000)		
Failure Predictable	Yes	No		Yes		No
Type of Maintenance						
Inspection/Lubrication	Y	Y		Y		Y
Preventive Maintenance (Task)	Y	Y		Y		N
Condition Monitoring	Y	N		N		N
Change Out On Life	N	Y		N		N
Run to Failure	N	N		Y		Y
Investigation of Breakdowns	Y	Y		N		N
Off-Site Repairs (Assuming can be done on site)						
Use Rotable						
Value of Rotable Stock	>$100K		$20-100K		<$20K	
Repair Time < 1 Day	N		N		N	
1-3 Days	N		N		N	
3-15 Days	N		N		Y	
>15 Days	Y		Y		Y	
Stock Holdings (Items< $20,000) (Whether to Hold Stock or Not)						
Value of Total Stock Holding	$2,000 - -$20,000		$500- -$2,000		<$500	
Failure Predictable?	Yes	No	Yes	No	Yes	No
Lead Time						
< 1 Day (Avail Ex. Stock-Local)	N	N	N	N	N	N
1-5 Days (Avail Ex. Stock-Country)	N	N	N	N	N	Y
5-15 Days	N	N	N	Y	Y	Y
>15 Days	Y	Y	Y	Y	Y	Y

	Criticality 4					
	No Impact on Production					
Differential Maintenance Cost of Failure	High (>$3,000)			Low (<$3,000)		
Failure Predictable	Yes	No		Yes		No
Type of Maintenance						
Inspection/Lubrication	Y	Y		Y		Y
Preventive Maintenance (Task)	Y	N		N		N
Condition Monitoring	N	N		N		N
Change Out On Life	Y	Y		N		N
Run to Failure	N	N		Y		Y
Investigation of Breakdowns	N	N		N		N
Off-Site Repairs (Assuming can be done on site)						
Use Rotable						
Value of Rotable Stock	>$100K		$20-100K		<$20K	
Repair Time < 1 Day	N		N		N	
1-3 Days	N		N		N	
3-15 Days	N		N		N	
>15 Days	N		N		N	
Stock Holdings (Items< $20,000) (Whether to Hold Stock or Not)						
Value of Total Stock Holding	$2,000 - -$20,000		$500- -$2,000		<$500	
Failure Predictable?	Yes	No	Yes	No	Yes	No
Lead Time						
< 1 Day (Avail Ex. Stock-Local)	N	N	N	N	N	N
1-5 Days (Avail Ex. Stock-Country)	N	N	N	N	N	N
5-15 Days	N	N	N	N	N	N
>15 Days	N	N	N	N	N	N

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GLOMACS International Partners with Oxford Management OXFORD MANAGEMENT CENTRE

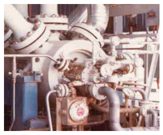
Reliability Based Maintenance Strategy Chart

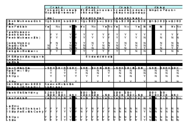
	Criticality 1				Criticality 2				Criticality 3				Criticality 4			
	Total product lost irretrievably Major Safety/Environmental Impact				Partial Production loss or loss of efficiency. Major Environmental Impact				Increased risk of production or efficiency loss. (Spared equip, by pass control valves etc.)				No Impact on Production			
Differential Maintenance Cost of Failure	High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)	
Failure Predictable	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Type of Maintenance																
Inspection/Lubrication	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Preventive Maintenance (Task)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	N
Condition Monitoring	Y	N	Y	N	Y	N	Y	N	Y	N	N	N	N	N	N	N
Change Out On Life	N	Y	N	Y	N	Y	N	N	N	Y	N	N	Y	Y	N	N
Run to Failure	N	N	N	N	N	N	N	Y	N	N	Y	Y	N	N	Y	Y
Investigation of Breakdowns	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N
Off-Site Repairs (Assuming can be done on site)					To be decided individually											
Use Rotable																

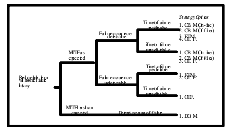
	Criticality 1			Criticality 2			Criticality 3			Criticality 4		
Value of Rotable Stock	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K
Repair Time < 1 Day	Y	Y	Y	N	N	N	N	N	N	N	N	N
1-3 Days	Y	Y	Y	N	N	Y	N	N	N	N	N	N
3-15 Days	Y	Y	Y	Y	Y	Y	N	N	Y	N	N	N
>15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N

	Criticality 1						Criticality 2						Criticality 3						Criticality 4					
Stock Holdings (Items< $20,000) (Whether to Hold Stock or Not)	Assumes no Rotable Stock held for the part																							
Value of Total Stock Holding	$2,000 - -$20,000		$500- -$2,000		<$500		$2,000 - -$20,000		$500- -$2,000		<$500		$2,000 - -$20,000		$500- -$2,000		<$500		$2,000 - -$20,000		$500- -$2,000		<$500	
Failure Predictable?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Lead Time																								
< 1 Day (Avail Ex. Stock-Local)	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
1-5 Days (Avail Ex. Stock-Country)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N
5-15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N	N	N	N
>15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N

Determining the Maintenance Strategy for an Equipment



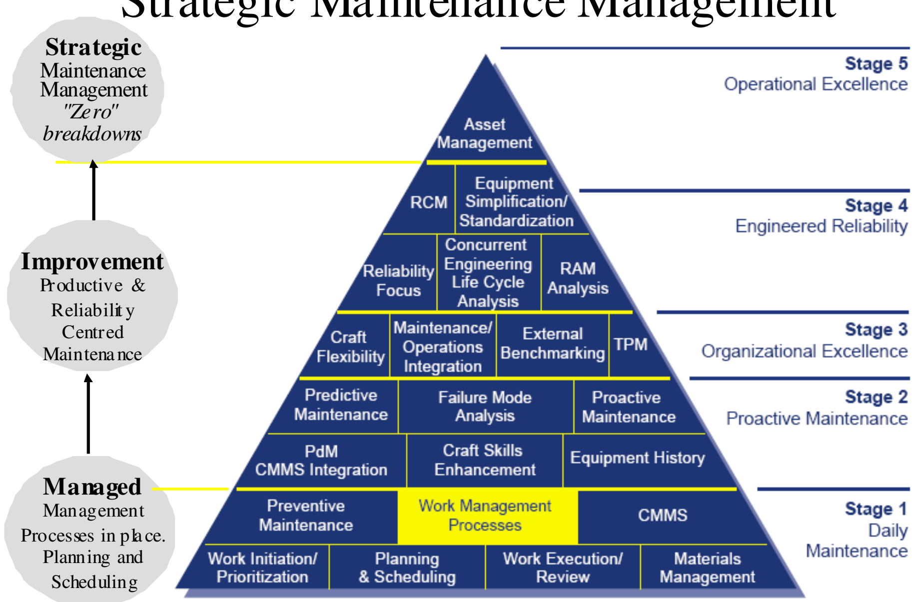




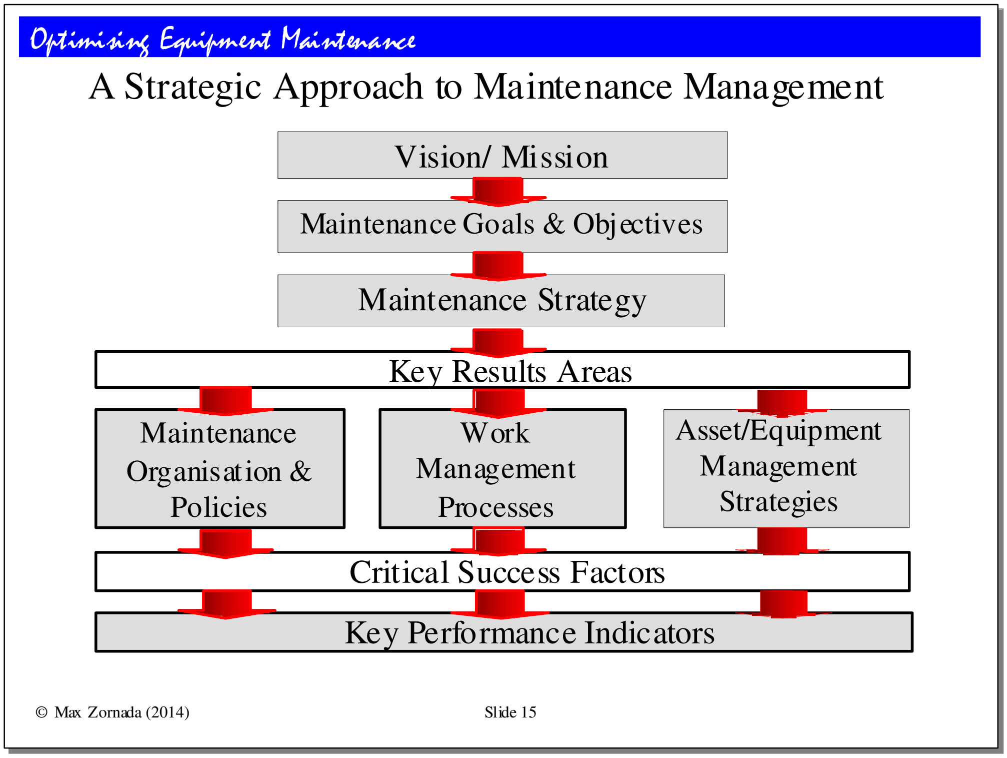
Select Equipment Item → Identify Maintenance Strategy Options → Validate against Failure characteristics → Decide if Rotable should be stocked → Decide if Spare Parts should be stocked

Determine Specific Task Details use recommended PM, RCM or PMO

Strategic Maintenance Management



Reference: S. Bradley Peterson, Strategic Asset Management, Inc.


Optimising Equipment Maintenance
A Strategic Approach to Maintenance Management
Vision/ Mission
Maintenance Goals & Objectives
Maintenance Strategy
Key Results Areas
Maintenance Organisation & Policies
Work Management Processes
Asset/Equipment Management Strategies
Critical Success Factors
Key Performance Indicators
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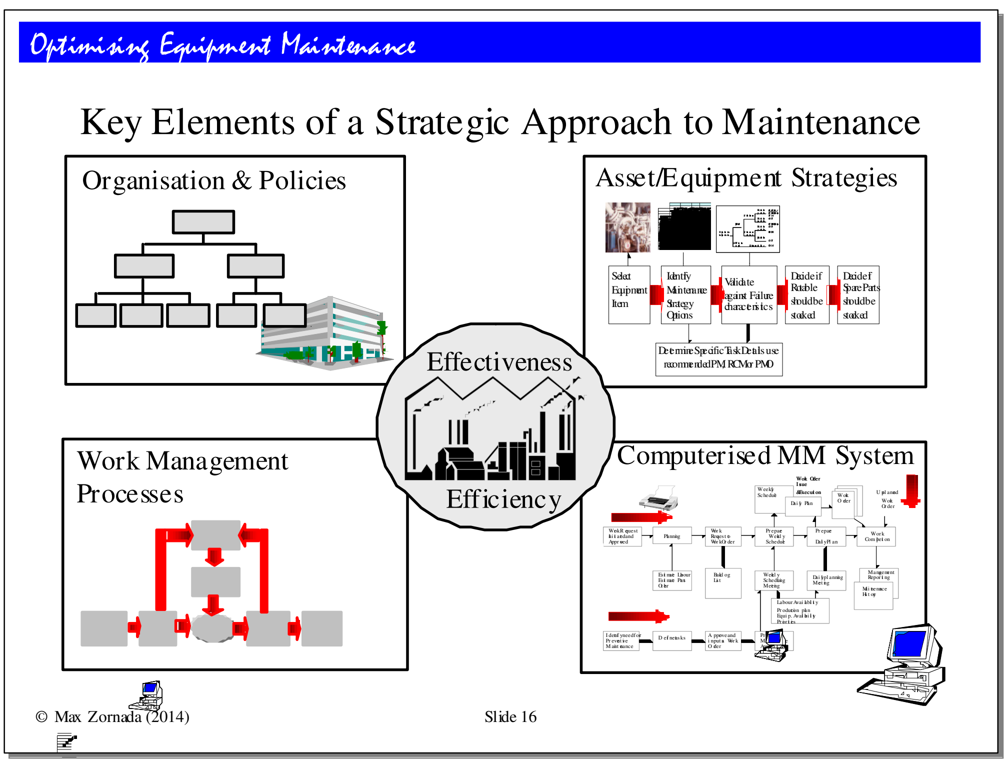
Optimising Equipment Maintenance
Key Elements of a Strategic Approach to Maintenance
Organisation & Policies
Asset/Equipment Strategies
Effectiveness
Efficiency
Work Management Processes
Computerised MM System
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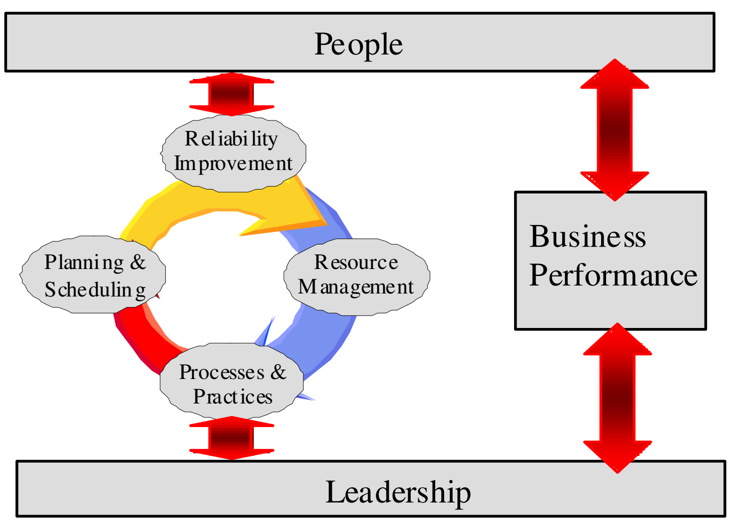
Maintenance Self-Assessment

Maintenance Excellence Framework

Maintenance Excellence Criteria



CONTENTS

Refer to the Criteria and Applications Guidelines booklet for suggestions on format for the AMEA submission.

INTRODUCTION

The Australian Maintenance Excellence Awards considers seven categories and related criteria:

- **Leadership**
- **People**
- **Planning and Scheduling**
- **Maintenance Processes and Practices**
- **Reliability Improvement**
- **Resource Management**
- **Business Performance**

By using these criteria, enterprises will be able to evaluate their capabilities of managing maintenance and its contribution to the business.

Through the Australian Maintenance Excellence Awards the IMRt seeks to provide a high quality process which acknowledges maintenance excellence, supports continuous improvement in the maintenance function, focusing on people, practices and the business impact of maintenance excellence.

Self-assessment has been recognised as a means of identifying and driving improvement opportunities by assessing current performance against a model of excellence.

This document is part of the companion set of Australian Maintenance Excellence Awards material which includes:

- Resource Booklet
- Criteria and Applications Guidelines
- Evaluation Team Booklet

This Self-Assessment Booklet is closely linked with the Resource Booklet. They are both more detailed than the Criteria and Applications Guidelines material. While covering the same categories and criteria the Criteria and Applications Guidelines material includes more general and broader questions and is intended to provide an opportunity for a more adaptive approach for Award assessment purposes. The Criteria and Applications Guidelines provide a suggested framework for a submission for the Australian Maintenance Excellence Awards. This Self Assessment booklet may be used as 'food for thought' when preparing a submission.

The Industrial Maintenance Roundtable (IMRt) wishes to acknowledge:

- EI DuPont de Nemours & Co who have provided insight and information gained through its Maintenance Excellence Recognition Process (MERP) and who very kindly made MERP material available to IMRt to assist the development of the Australian Maintenance Excellence Awards.
- the Australian Quality Council for its support and expert advice given freely to the IMRt during the development of The Australian Maintenance Excellence Awards.
- the National Minerals Industry Excellence Award for Safety and Health which provided a model for the development of this award.

Refer to the Criteria and Applications Guidelines booklet for suggestions on format for the AMEA submission.

THE SELF-ASSESSMENT PROCESS

It is recommended that to be most effective, the self-assessment process be carried out in a structured workshop, with a cross-functional team, and facilitated by a trained assessor.

The workshop, during the self-assessment process, provides an assessment of where the enterprise is today compared to the maintenance excellence model. It also provides quantitative data through the questionnaire and also qualitative data on the current position of the enterprise.

A feedback report can be collated from this data which is also used as a basis for planning improvement.

Typical work sheets have been provided to assist with the analysis, refer to pages 15 and 16.

CATEGORIES & CRITERIA

1. LEADERSHIP (14% of total)

The intent of this Category is to cover the role of leadership in the development of the maintaining function within the organisation at a corporate and enterprise level.

		1	2	3	4	5
a.	Planned maintenance is part of our written business philosophy, mission or aim.	❐	❐	❐	❐	❐
b.	We have written goals, objectives and measures that document continued improvement of the maintenance function's contribution to the business.	❐	❐	❐	❐	❐
c.	There is a leadership network that provides guidance and direction for continual functional improvement of the maintenance function.	❐	❐	❐	❐	❐
d.	Reports measuring planned maintenance performance, i.e., key parameters VS goal are periodically issued.	❐	❐	❐	❐	❐
e.	Company reference documents, such as "Maintenance Procedures" and "Engineering Standards" are routinely adhered to.	❐	❐	❐	❐	❐

Column Total					
Multiply by	**1**	**2**	**3**	**4**	**5**
=					

Category Total		**Addition of the above**
Category, % Max. Score		**Category Total/25 x 100%**
Category Total, Weighted		**Category Total x 14/25**

2. PEOPLE (18% of total)

The intent of this category is cover the extent to which the organisation provides people at all levels in the enterprise with the appropriate skills, and engenders the commitment required to achieve the maintenance goals and objectives.

		1	2	3	4	5
a.	A long-range strategic plan for maintenance is in place that defines what the maintenance job will look like, what skills will be necessary and how these skills will be acquired.	❒	❒	❒	❒	❒
b.	A job analysis that defines required skills has been conducted and is updated periodically.	❒	❒	❒	❒	❒
c.	Resource persons available to answer questions during the training process and available to assist in developing troubleshooting skills with skills demonstrations.	❒	❒	❒	❒	❒
d.	A formal program to refresh the skills of trades people and to introduce new skills is in place.	❒	❒	❒	❒	❒
e.	A formal cross-training plan is in place to develop versatility in the workforce.	❒	❒	❒	❒	❒
f.	A means of measuring results, such as task-certification programs and detailed training records to track the effectiveness of the program are in place.	❒	❒	❒	❒	❒
g.	A means to train maintenance supervisory personnel in maintenance best practices and systems.	❒	❒	❒	❒	❒
	Column Total					
	Multiply by	**1**	**2**	**3**	**4**	**5**
	=					

Category Total		**Addition of the above**
Category, % Max. Score		**Category Total/35 x 100%**
Category Total, Weighted		**Category Total x 18/35**

3. PLANNING AND SCHEDULING (11% of total)

The intent of this category is to cover how the enterprise develops, implements, controls, measures and improves its planning and scheduling of its maintenance work to achieve the corporate objectives.

		1	2	3	4	5
a.	Production, maintenance and technical strongly support the concept of planned and scheduled maintenance and, as partners, are committed to its success.	❐	❐	❐	❐	❐
b.	A team dedicated to the planning, scheduling and coordinating of routine maintenance work is in place.	❐	❐	❐	❐	❐
c.	Preventive and predictive maintenance work is an integral part of this P&S effort.	❐	❐	❐	❐	❐
d.	Routinely, the right materials and resources are brought together at the right place and the right time to work on properly prepared equipment.	❐	❐	❐	❐	❐
e.	Repairs are promptly made when indicated by trend analysis.	❐	❐	❐	❐	❐
f.	Inspection records include:					
	1. Inspection checklists and routes	❐	❐	❐	❐	❐
	2. Inspection frequency	❐	❐	❐	❐	❐
g.	Systems are in place which ensure action is taken when inspections and repairs do not occur as scheduled.	❐	❐	❐	❐	❐
h.	Systems are in place which:					
	1. Describe the nature of the repair	❐	❐	❐	❐	❐
	2. Provide instructions to craftsmen	❐	❐	❐	❐	❐
	3. Record what repairs were completed	❐	❐	❐	❐	❐
	4. Collect labor and materials charges	❐	❐	❐	❐	❐
	5. Track downtime	❐	❐	❐	❐	❐

3. PLANNING AND SCHEDULING (11% of total) continued …

i.	Records for inspections and repairs meet requirements of local codes and corporate standards (pressure vessels, boilers, expansion joints, etc).	❐	❐	❐	❐	❐
	Column Total					
	Multiply by	**1**	**2**	**3**	**4**	**5**
	=					

Category Total		**Addition of the above**
Category, % Max. Score		**Category Total/70 x 100%**
Category Total, Weighted		**Category Total x 11/70**

4. MAINTENANCE PROCESSES AND PRACTICES (16% of total)

The intent of this category is to cover how the enterprise establishes, implements, monitors, analyses and improves its preventive, predictive and reactive maintenance systems to meet the goals of the organisation.

		1	2	3	4	5
a.	A formal, periodic equipment inspection system is in place that is consistent with manufacturers' specifications and in compliance with government regulations.	❐	❐	❐	❐	❐
b.	Predictive maintenance inspection routes have been established and inspections are made on schedule.	❐	❐	❐	❐	❐
c.	Inspections are always carried out exactly as specified and at the specified inspection frequency.	❐	❐	❐	❐	❐
d.	Discrepancies are always corrected before the process/equipment is returned to operation.	❐	❐	❐	❐	❐
e.	A lubrication program is in place to ensure equipment is lubricated routinely and adequately with the proper lubricant.	❐	❐	❐	❐	❐
f.	Critical equipment (based on impact on safety, production, quality, environment, cost etc) have been identified and listed for the purpose of applying predictive maintenance techniques.	❐	❐	❐	❐	❐
g.	Alert and danger limits for parameters have been established and published.	❐	❐	❐	❐	❐
h.	Records are formalised and trend analysis is routinely used to monitor equipment condition.	❐	❐	❐	❐	❐
i.	A system of inspections have been developed for:					
	1. Noise level	❐	❐	❐	❐	❐
	2. Leaks or emissions	❐	❐	❐	❐	❐
	3. Hot spots	❐	❐	❐	❐	❐
	4. Physical condition (paint, corrosion, loose parts, missing nuts or bolts, deteriorated insulation, etc)	❐	❐	❐	❐	❐
j.	A system is in place to ensure that inspections occur.	❐	❐	❐	❐	❐

4. MAINTENANCE PROCESSES AND PRACTICES (16% of total) continued …

		1	2	3	4	5
k.	Equipment specifications are maintained and are easily retrieved when needed.	❒	❒	❒	❒	❒
	Column Total					
	Multiply by	**1**	**2**	**3**	**4**	**5**
	=					

Category Total		**Addition of the above**
Category, % Max. Score		**Category Total/70 x 100%**
Category Total, Weighted		**Category Total x 16/70**

5. RELIABILITY IMPROVEMENT (18% of total)

The intent of this category is to cover how the enterprise establishes and maintains a focus on the needs of the business in particular on the reliability improvement process using problem solving techniques, increasing uptime, improving yields and process reliability and assuring quality.

		1	2	3	4	5
a.	Records are maintained and periodically audited to ensure preventive maintenance is performed on each piece of equipment as intended.	❐	❐	❐	❐	❐
b.	A long-range program is in place that enhances equipment reliability through:					
	1. Initial design to enhance maintainability through life cycle cost analyses.	❐	❐	❐	❐	❐
	2. Proper operation of equipment during its normal life span.	❐	❐	❐	❐	❐
c.	A formal system exists to attack equipment problems that includes:					
	1. Identification and qualification of the problem and definition of the underlying root cause.	❐	❐	❐	❐	❐
	2. Long-term corrective action.	❐	❐	❐	❐	❐
	3. Effective tracking of corrective action to ensure success.	❐	❐	❐	❐	❐
d.	Measures that emphasise uptime are identified, collected, tracked and reported throughout the organisation.	❐	❐	❐	❐	❐
e.	Equipment performance and maintenance history are stored and used to trend reliability, repair frequencies, failure modes, mean time to failure, etc.	❐	❐	❐	❐	❐
	Column Total					
	Multiply by	**1**	**2**	**3**	**4**	**5**
	=					

Category Total		**Addition of the above**
Category, % Max. Score		**Category Total/40 x 100%**
Category Total, Weighted		**Category Total x 18/40**

6. RESOURCE MANAGEMENT (11% of total)

The intent of this category is to cover the management of materials, contracts and consultants and how the enterprises establishes, implements, monitors, analyses and improves its materials and resources under contract.

		1	2	3	4	5
a.	Where appropriate, integrated supply, vendor stocking, vendor consignment, vendor direct delivery, etc are a part of the overall materials management process.	❐	❐	❐	❐	❐
b.	Rebuilding programs for appropriate items (motors, valves, seals, etc) are operational.	❐	❐	❐	❐	❐
c.	An alternative materials procurement is in place and used where appropriate.	❐	❐	❐	❐	❐
d.	Corporate convergence efforts are supported and the EEA (Effective Equipment Acquisition) agreements are utilised where appropriate.	❐	❐	❐	❐	❐
e.	Measurement techniques for stores performance (investment, service, utilisation, etc) are routinely used.	❐	❐	❐	❐	❐
f.	Equipment parts lists are readily available.	❐	❐	❐	❐	❐
g.	There is a site materials improvement cross-functional network that provides direction and processes improvement opportunities for maintenance requisition order materials	❐	❐	❐	❐	❐
h.	Electronic means for procurement is maximised where functional capability exists.	❐	❐	❐	❐	❐
i.	Site principles are in place that define what work is contracted and what is kept in-house.	❐	❐	❐	❐	❐
j.	A training program for contract administrators that covers all aspects of contractor monitoring is in place.	❐	❐	❐	❐	❐
k.	An audit system is in place to monitor the quality, productivity, and cost of work performed by contractors.	❐	❐	❐	❐	❐
l.	A contractor selection process is in place that considers capabilities, types of contracts, best practices, and corporate guidelines.	❐	❐	❐	❐	❐

6. RESOURCE MANAGEMENT (11% of total) continued…

m.	An effective working relationship that supports continuous improvement is built with primary contractors.	❒	❒	❒	❒	❒

Column Total						
Multiply by	**1**	**2**	**3**	**4**	**5**	
=						
Category Total		**Addition of the above**				
Category, % Max. Score		**Category Total/65 x 100%**				
Category Total, Weighted		**Category Total x 11/65**				

7. BUSINESS PERFORMANCE (12% of total)

The intent of this category is to cover the extent to which the operation demonstrates sustained improvement to the key objectives and performance indicators and how this contributes to the overall performance of the organisation.

		1	2	3	4	5
a.	Goals have been set and performance is measured and reported throughout the organisation; corrective action is aimed at continued improvement.	❐	❐	❐	❐	❐
b.	Performance reports exist that show progress toward a long-range strategic plan for maintenance.	❐	❐	❐	❐	❐
c.	Where maintenance of a facility impacts quality, it is identified, measured and reported: e.g., out of tolerance or variable tolerance product associated with machine breakdown or out of tolerance equipment.	❐	❐	❐	❐	❐
d.	Where maintenance of a facility impacts the amount of product produced, it is identified, measured and reported, i.e., rate reduction or scrap associated with machine breakdown or out of tolerance equipment.	❐	❐	❐	❐	❐
j.	Where maintenance of a facility impacts bottom line cost, it is identified, measured and reported, i.e., cost reductions through improved maintenance procedures/programs.	❐	❐	❐	❐	❐
	Column Total					
	Multiply by	1	2	3	4	5
	=					

Category Total		**Addition of the above**
Category, % Max. Score		**Category Total/25 x 100%**
Category Total, Weighted		**Category Total x 12/25**

Refer to the Criteria and Applications Guidelines booklet for suggestions on format for the AMEA submission.

SELF-ASSESSMENT SCORING GUIDELINES

Each question within a section is weighed equally. Points are assigned as follows:

1 = No system in place

2 = System planning beginning

3 = System planning complete

4 = System implemented

5 = System implemented and mature

Results provide a general guide relative to Maintenance Excellence scoring and help identify areas for improvement opportunities.

SELF-ASSESSMENT SCORING

It should be noted that the score in and of itself is not important. What is important is that this self-assessment process provides an opportunity to identify which best practice areas require most attention for improvement and which are strongest.

The questions may also provide guidance regarding particular strengths and opportunities for improvement. A page to assist with this exercise is included on page 16.

The process for identifying opportunities can be assisted by the data summary chart on page 15 which shows:

- the percentage of the maximum score for each category (% Category Max. Score);
- the weighted category score; and
- the relative ranking of each category score.

USE OF THE SCORING SYSTEM

Scores are used to analyse relative ranking of each category.

- Low scores indicate categories for improvement opportunities;
- High scores indicate strengths;
- Gap between scores and maximum possible scores attainable indicate opportunities for improvement in striving to achieve excellence.

SCORE TABLE

Category	Category Total	Category, % Max. Score	Weighted Score	Relative Ranking
Leadership				
People				
Planning and Scheduling				
Maintenance Processes and Practices				
Reliability Improvement				
Resource Management				
Business Performance				

Refer to the Criteria and Applications Guidelines booklet for suggestions on format for the AMEA submission.

IMPROVEMENT OPPORTUNTIES TABLE

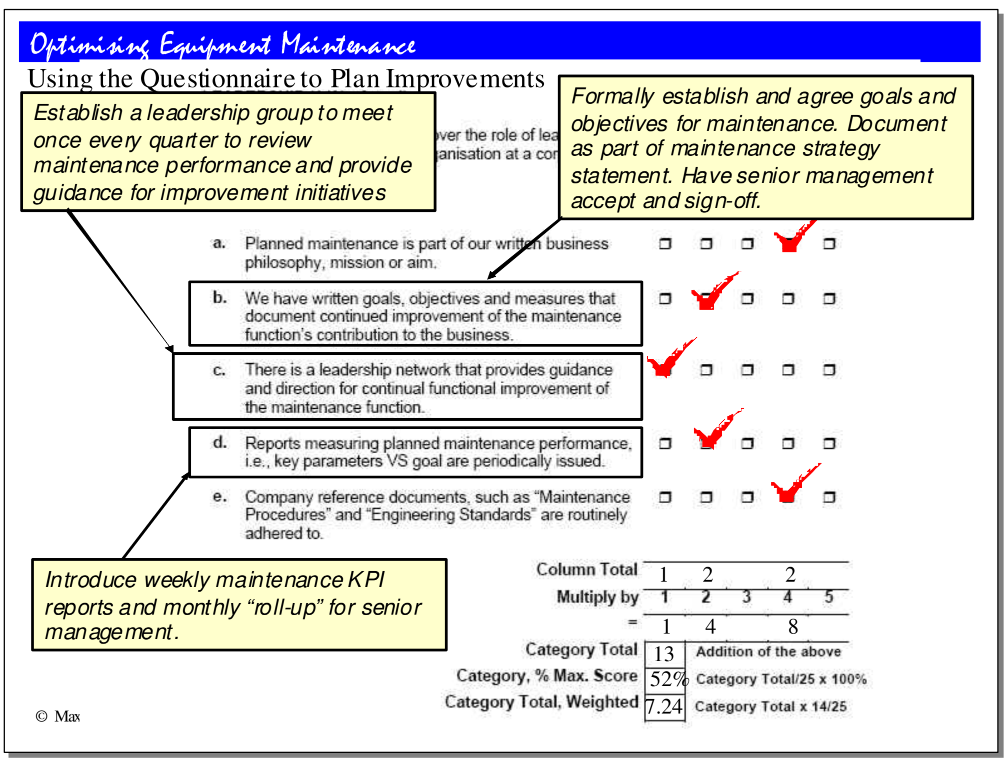
Category	Strengths	Opportunities

Optimising Equipment Maintenance

Using the Questionnaire to Plan Improvements

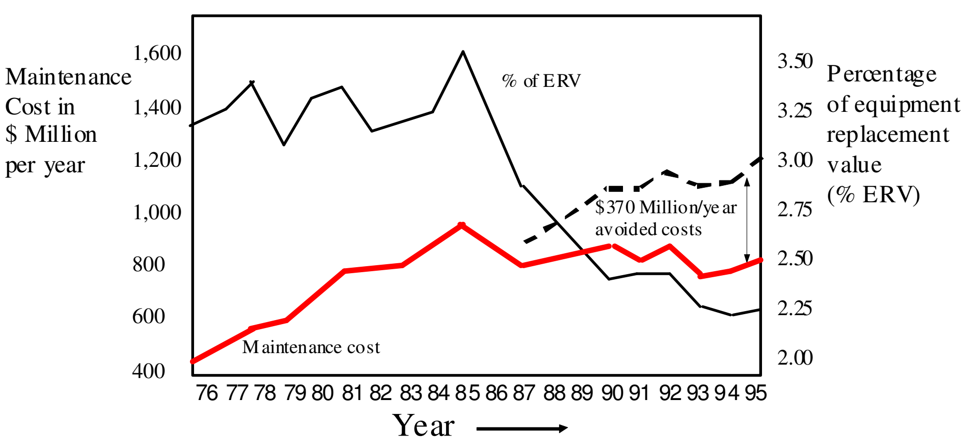
- Identify which areas scored the lowest scores;
- Look at the detailed questions in that section and focus on the ones that score low (eg. 1 or 2)
- Read the question and determine what requirements are implied by the question;
- Determine what you would need to do to improve your score;
- Work through with other questions and other sections.

 Slide 1



Maintenance Best Practice Benchmarks Review

Du Pont - Maintenance Cost Trends

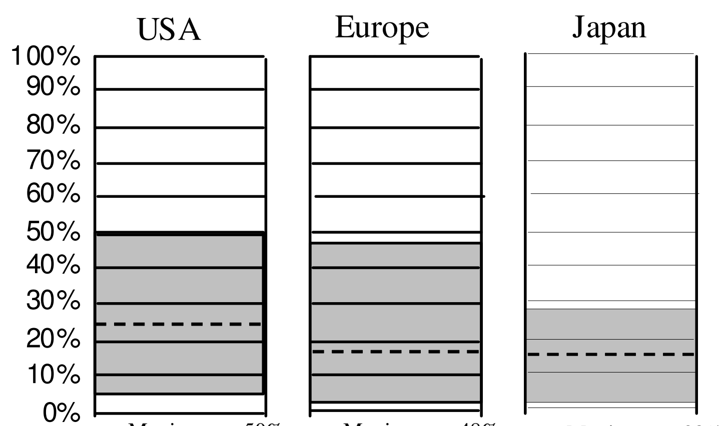


A Sampling of the Du Pont Benchmarks

What they found

Maintenance Workers as a % of Total Plant Workers

The number of maintenance hourly paid workers required to support production.



- Maximum = 50%
- Minimum = 5%
- Average = 25%

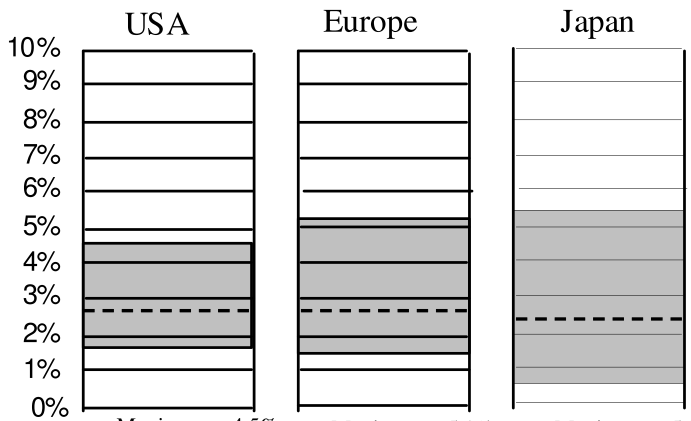
- Maximum = 48%
- Minimum = 2%
- Average = 18%

- Maximum = 28%
- Minimum = 2%
- Average = 15%

Optimising Equipment Maintenance

Maintenance Cost as a % of Estimated Replacement Value

A summary of cost-effectiveness. A continual downward trend without real improvement in maintenance can reflect milking of assets.



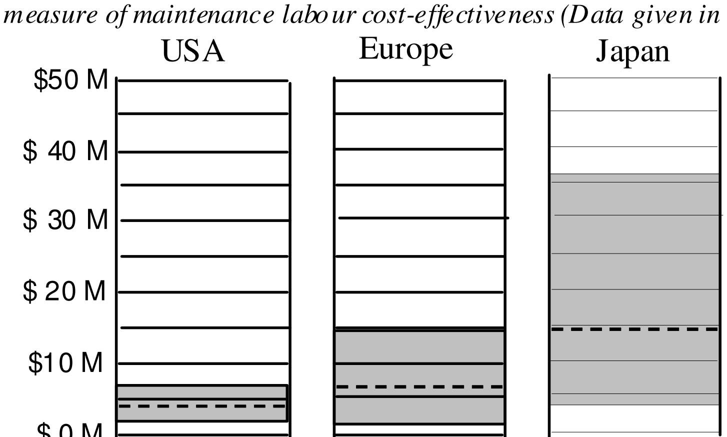
USA	Europe	Japan
• Maximum = 4.5%	• Maximum = 5.1%	• Maximum = 5.3%
• Minimum = 1.8%	• Minimum = 1.5%	• Minimum = 0.7%
• Average = 2.9%	• Average = 2.8%	• Average = 2.3%

 Slide 7

Optimising Equipment Maintenance

Value of Assets Maintained by each maintenance employee.

A measure of maintenance labour cost-effectiveness (Data given in USD)



USA	Europe	Japan
• Maximum = $6.5M	• Maximum = $14.8M	• Maximum = $36.1M
• Minimum =$2.1M	• Minimum = $2.0M	• Minimum = $3.8M
• Average = $4.1M	• Average = $6.8M	• Average = $ 14.5M

 Slide 8

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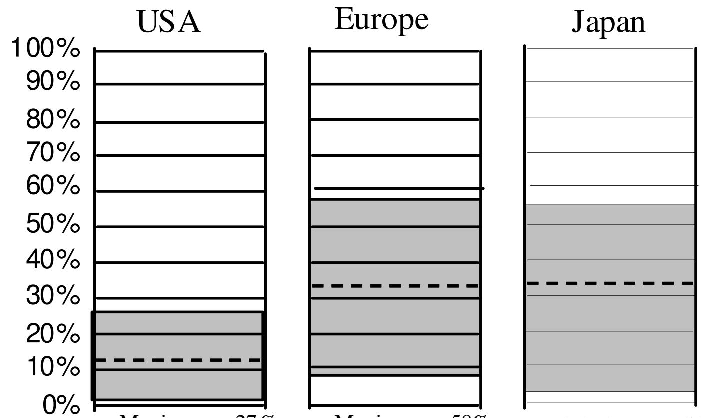
Optimising Equipment Maintenance

Contractor Costs as a % of Total Maintenance Costs

Indicator to be monitored over several years to show trends in contractor use.



- USA: Maximum = 27%
- Minimum = 1%
- Average = 12%

- Europe: Maximum = 58%
- Minimum = 9%
- Average = 32%

- Japan: Maximum = 55%
- Minimum = 2%
- Average = 33%

Optimising Equipment Maintenance

Stores Investment as a % of Estimated Replacement Value

A measure of stores inventory management

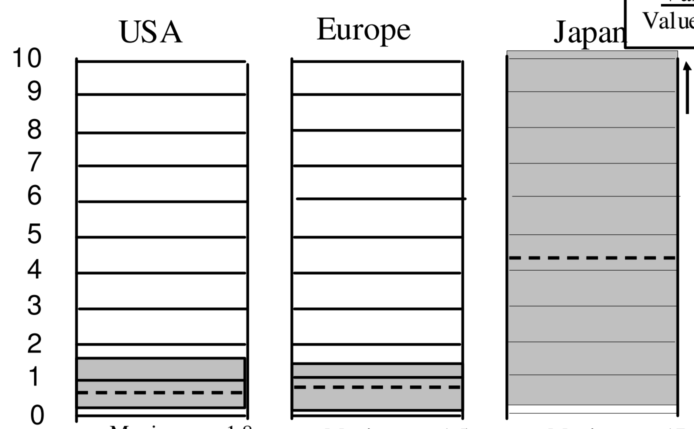
- USA: Maximum = 1.9%
- Minimum = 0.5%
- Average = 1.2%

- Europe: Maximum = 2.2%
- Minimum = 0.05%
- Average = 0.9%

- Japan: Maximum = 0.75%
- Minimum = 0.01%
- Average = 0.52%

Stores Annual Stock Turns

Definition
Stock Turn
= Value of Issues
Value of Stock Holding



USA:
- Maximum = 1.8
- Minimum = 0.2
- Average = 0.7

Europe:
- Maximum = 1.5
- Minimum = 0.1
- Average = 0.8

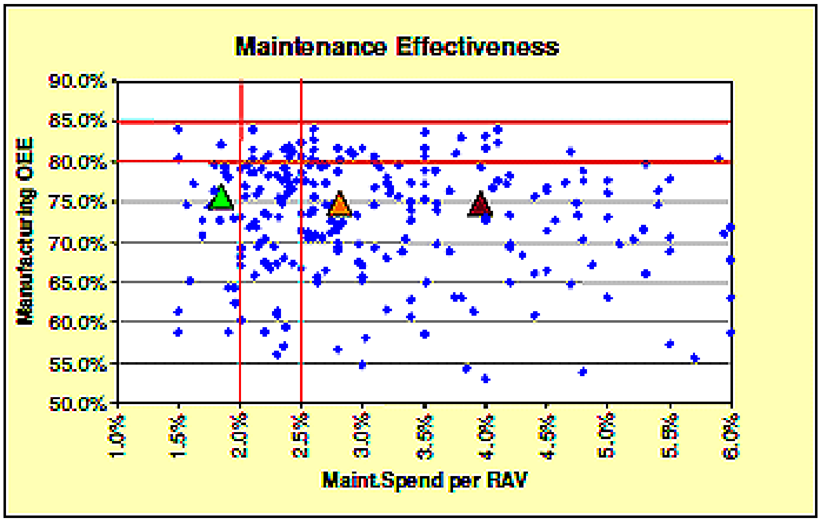
Japan:
- Maximum = 17
- Minimum = 0.2
- Average = 4.3

2006 Maintenance Benchmarking Study

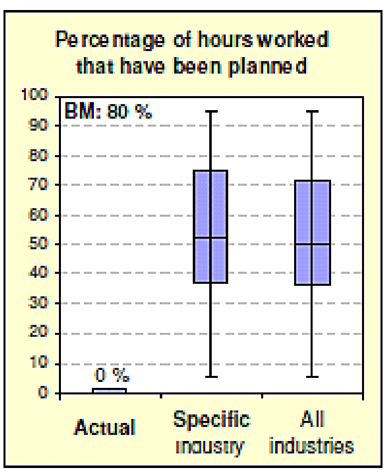
included following participants

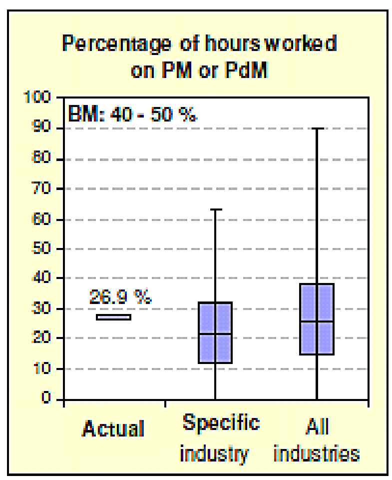
- CMS, Chile
- BlueScope Steel, Australia
- Hydro Aluminium, Australia
- Kunda Nordic Cement, Estonia
- Mondo Minerals, Finland (3 sites)
- Boliden Harjavalta, Finland
- Outokumpu Poricopper, Finland
- OMG Harjavalta Nickel, Finland
- JaRo, Finland
- ABB Motors, Finland
- ABB Industry, Finland
- ABB Motors, Estonia
- DMS, South Africa
- MMC, South Africa
- Columbus Steel, South Africa
- Outokumpu Stainless, Sweden
- Alcan, UK

Maintenance Effectiveness

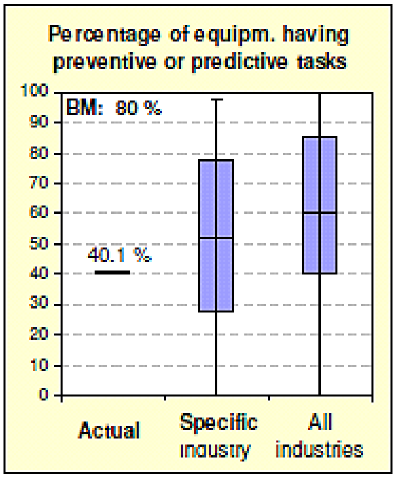


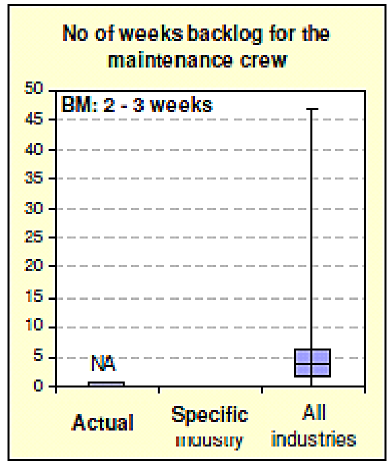
Planned work and PM hours





PM Coverage and Backlog





Foundations of Reliability

Reliability: A Definition

- A probability;
- Probability that a part or product will function properly for a given length of time.

Optimising Equipment Maintenance

Tactics for Reliability and Maintenance

- Reliability Tactics
  - – improving individual components
  - – providing redundancy
- Maintenance Tactics
  - – implementing preventive maintenance
  - – increasing repair capabilities

 Slide 3

Optimising Equipment Maintenance

Measuring Failure Rates

- Failure Rate:
  - – FR(%): # of failures / # tested in percent
  - – Example: test 200 items, 4 fail,
    - FR(%)=2%
- FR(N): = # of failures / operating time
- Example: Test 25 light bulbs for 1500 hours. 5 fail at 500, 700, 750, 800, and 1200 hours
  - – Total operating time = (20x1500)+3950=33950
  - – FR(N) = 5/33950=0.000147275 failures per hr.

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Example, Continued

- Suppose you have 100 light bulbs that will be used for 1000 hours
- How many would you expect to fail?
- FR(N)x100x1000=14.72 bulbs

Mean Time Between Failures

- MTBF=1/FR(N)
  - for our example, 1/FR(N) = 6,790 hours

Summary of Definitions

- Reliability:
  - Probability that an item will function for a given time;
- Mean time between failures (MTBF):
  - Average time between failures of a repairable item;
- Failure rate:
  - Reciprocal of MTBF.

Quantifying Reliability

$$\text{Reliability} = e^{-(fr * t)}$$

Where:
e = 2.718
fr = failure rate during a fixed period
t = the duration of the fixed period.

Reliability Example

- Recall our light globes:
  - FR(N) = 5/33950=0.000147275 failures per hr

Reliability = $e^{-(0.000147275 * 1)}$

Per hour, so time period is 1 hour.

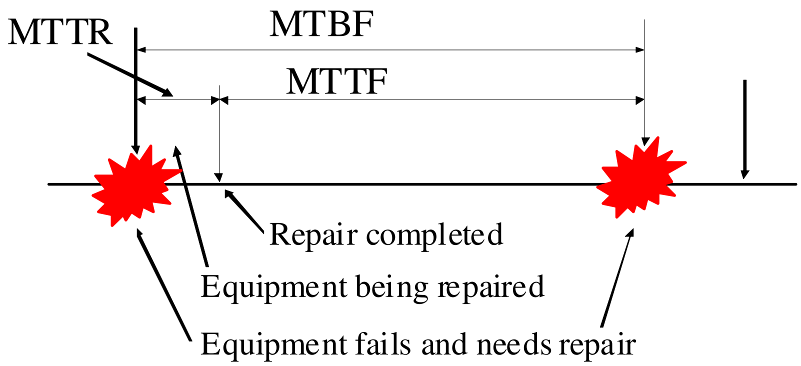
Reliability = 0.9999 = 99.99%

Some more definitions

- Mean Time To Repair (MTTR)
  - The average time is takes to repair something after a failure;
- Mean Time To Failure (MTTF)
  - Is the time from when the repair is completed and the next failure;
  - Also referred to as Mean Time Between Repairs (MTBR)

Optimising Equipment Maintenance

MTBF, MTTR and MTTF



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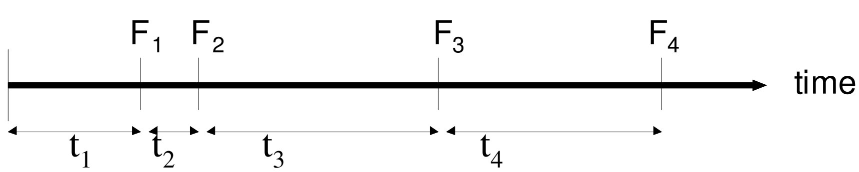
Optimising Equipment Maintenance

MTBF and MTTF



t_0 = start time
t_1 … t_4 = operating times 1 through 4
F_1 … F_4 = failures 1 through 4

$$\text{MTBF} = \frac{t_1 + t_2 + t_3 + \ldots + t_n}{n}$$

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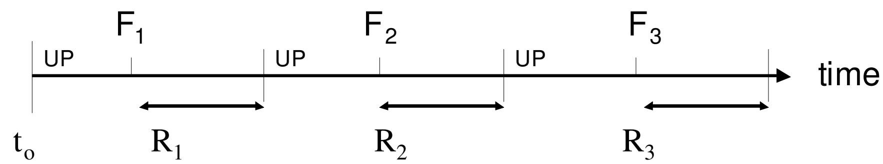
Mean Time to Repair



t_0 = start time
$F_1 \ldots F_3$ = failures 1 through 3
$R_1 \ldots R_3$ = repair times 1 through 3

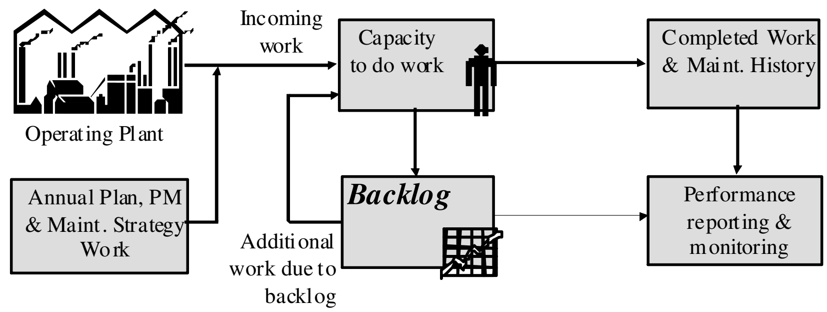
$$MTTR = \frac{R_1 + R_2 \ldots + R_n}{n}$$

Optimising Equipment Maintenance

MTTF, MTTR etc….

- MTTF = MTBF - MTTR
- Is a better measure of improving reliability because:-
  - Poor maintainability (i.e. making repairs take longer) results in a longer MTTR and extends the MTBF for a given MTTF.
- MTTR is used as a measure of maintainability - i.e. how fast are repairs complete;
- Downtime = $\frac{MTTR}{MTBF}$

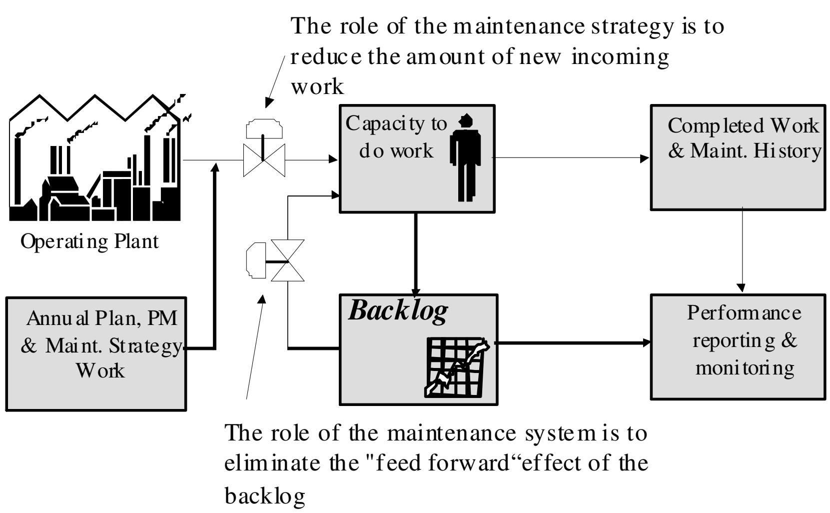
Maintenance Management as a Dynamic Process



Work Identification	Work Management	Monitoring & Analysis
Maintenance Strategy Predictive & Preventive Maintenance Work Order System	Planning & scheduling Backlog Management Integration with production	Reliability Improvement Objective setting Continuous Improvement

Optimising Equipment Maintenance

Maintenance Strategy vs Maintenance System



Measuring Maintenance Performance

A Typical Week in Maintenance

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A Typical Week in Maintenance

After meeting with the production supervision to discuss the week's production priorities and maintenance requirements, the maintenance supervisor prepares a weekly schedule for his work group.

After preparing the schedule, he notes that a total of ***319 Estimated Labour Hours*** of work have been scheduled. This represent a little over 50 % of his permanent workforce, which he feels should be achievable.

The week passes by like weeks usually do, and his schedule ends up being "blown out the water" as it is during most weeks. Additional jobs came up during the week in the form of urgent breakdowns, that forced him to reallocate tradespeople who had originally been allocated to scheduled work, to attend to these breakdowns.

Other jobs from the backlog, which had not been given priority at the weekly scheduling meeting suddenly became urgent requiring several unscheduled "backlog" jobs to be done in favour of scheduled work.

It was time to review just how badly things had gone before his manager "collars" him over some aspect of the week's schedule.

He uses his computerised maintenance management system to dial up a listing of total work done during the week. He notes that the total number of actual labour hours booked to jobs completed during the schedule week was ***280 Actual Hours.*** This included all jobs done regardless of whether they had been planned or scheduled or even known about in advance before being done.

Already things didn't look too good. The labour report indicated that even after allowing for the few sickies that were taken during the week and absence of the two fitters who attended a training course for most of the week, ***540 Actual Hours*** were available for work in his department during the schedule week.

Where had all the hours gone ?

Closer examination of the work done list revealed that a reasonable portion of the work originally scheduled was actually done. In fact, ***171 Estimated Hours*** had been cleared from the scheduled and the total hours booked to complete these jobs was ***175 Actual Hours.***

Comparing the 175 actual hours to the 280 actual hours indicating the total work done, suggested that an additional 105 actual hours of work was done on jobs that had not been anticipated when the schedule was originally put together.

A quick scan through all the jobs that had been estimated prior to completion, which would suggest someone had looked at them in advance and done at least some degree of planning, revealed that a total of ***210 Estimated Hours*** had been completed from the backlog during the week. Furthermore, these jobs with estimates had ***221 Actual Hours*** booked against them.

A look at preventive maintenance specifically, revealed that of the work originally scheduled ***80 Estimated Hours*** had been PM. Of these, ***76 Estimated Hours*** had taken ***82 Actual Hours*** to complete. This looked good. However, the total hours of PM that had been missed indicated that total overdue preventive maintenance from previous weeks added upto 15 hours, add to this the 4 hours from the week just gone, brought the overdue PM to 19 hours for the year.

A check of the existing backlog indicated that ***625 Estimated Hours*** of work were still registered on the backlog and that an additional ***145 Estimated Hours*** of preventive maintenance would fall due within the next 2 schedule weeks.

As he looked up from his computer screen, he could see the Maintenance Manager coming through the door at the opposite end of the workshop and striding in his direction. It was times like these that he wished the back door to his office had not been sealed off when they relocated the tool store.

Discussion Question

Without attempting to do any in-depth calculations on the figures given what are you initial thoughts about the situation described ?

A Summary of the Week's Numbers

A	Actual hours booked against all jobs done	280
B	Actual hours booked against jobs with estimates	221
C	Estimated hours cleared from the schedule	171
D	Estimated hours originally scheduled	319
E	Actual hours spent on scheduled work	175
F	Estimated hours of PM cleared from the schedule	76
G	Estimated hours of PM originally scheduled	80
H	Actual hours spent working on PM	82
	Overdue PM	19
I	Estimated hours completed	210
J	Actual hours on planned jobs	221
K	Estimated hours still to do at the end of the week	625
L	PM due during the next 2 weeks	145
M	Total Backlog Hours	770
N	Total Hours of Labour Available during the week	540

Maintenance KPI's

% Planned Work = Planned Work Done (B) / Total Work Done (A) = 221 / 280

= 79%

Schedule Achievement = Est Hours Sched. Work Done (C) / Est Hours Scheduled (D) = 171 / 319

= 54%

% Scheduled = Act Hours on Sched Work Done (E) / Total Work Done (A) = 175 / 280

= 63%

Maintenance KPI's (Continued)

PM Schedule ach'vmnt = Est. Hours of PM Scheduled & Completed (F) / Est. Hours of PM originally scheduled (G)

= 76 / 80 = 95%

% PM = Act Hours on PM (H) / Total Work Done (A) = 82 / 280

= 29%

Overdue PM = 19 Hours

Maintenance KPI's (Continued)

Estimating Index $= \dfrac{\text{Est Hours on Planned Work (I)}}{\text{Actual Hours on Planned Work (J)}}$

$= \dfrac{210}{221}$

$=$ 95%

Maintenance KPI's (Continued)

Backlog in hours

= Estimated Hours outstanding work + next 2 weeks PM

= 625 + 145 = 770 Hours

Backlog load in weeks

$= \dfrac{\text{Estimated Hours Outstanding}}{\text{Total Hours Done This Week x EI}} = \dfrac{770}{280 \text{ X } 0.95}$

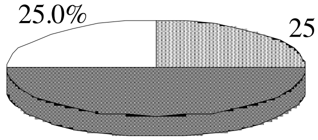
= 2.9 weeks

Optimising Equipment Maintenance

Typical Use of Trades Time

For Unplanned Reactive Maintenance

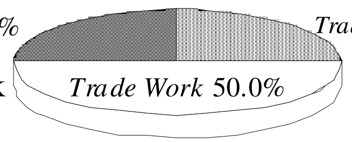
Trade Related
Inspect, Troubleshoot, Calibrate, Adjust, Make-up parts, Test, Etc.



Trade Work
Dismantle, Replace parts, reassemble etc.

Delays
Waiting for parts/materials, incorrect tools, wrong spares, awaiting other trades, hold-ups by operations, area not prepared, insufficient lifting gear, no/wrong information, etc.

For Planned & Scheduled Work



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Optimising Equipment Maintenance

Improving Maintenance Efficiency

Majority of work is reactive. Maintenance labour utilisation 20 - 25% on average	Some work is reactive. Labour utilisation 20 - 25%. Planned and scheduled 50 - 60 % labour utilisation.	Minimal reactive work. Majority of work is planned and scheduled 50-60% labour utilisation

Supported by the use of an effective computerised maintenance management information system and the introduction of backlog management, planning and weekly scheduling practices

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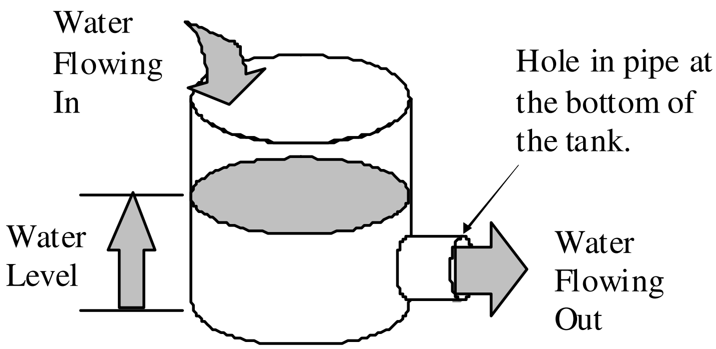
Optimising Equipment Maintenance

The Flow View of Processes

The Water Tank Analogy



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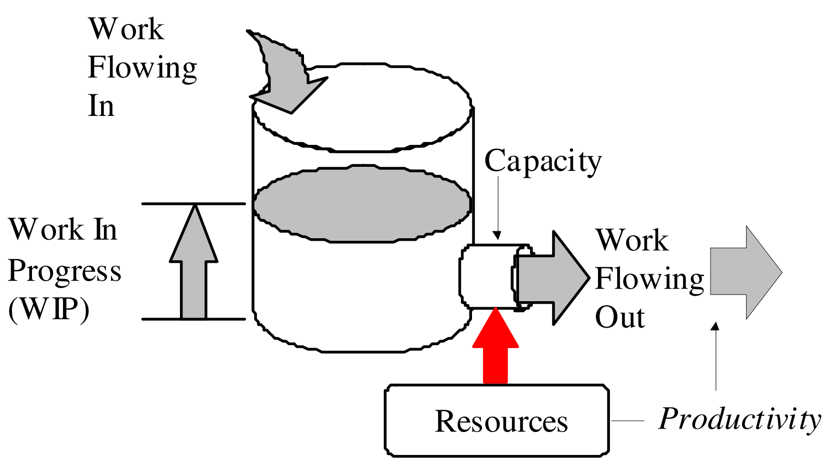
Optimising Equipment Maintenance

Workflow Process Management Model



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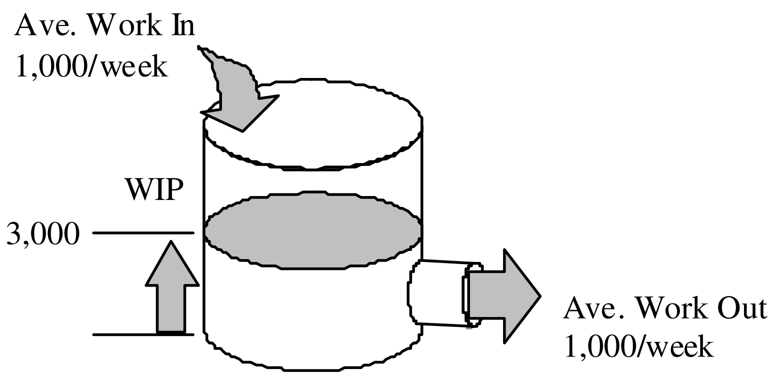
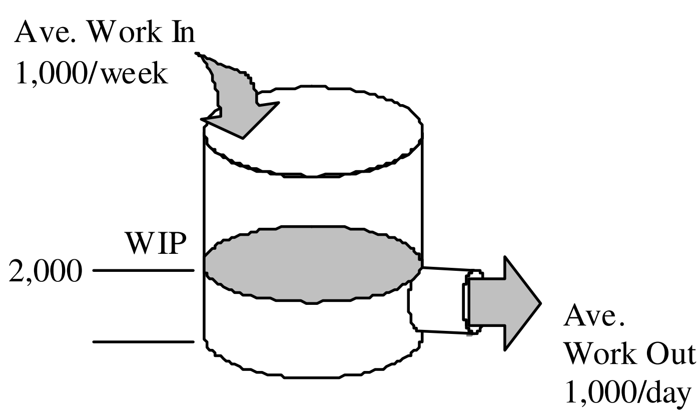
What about .....

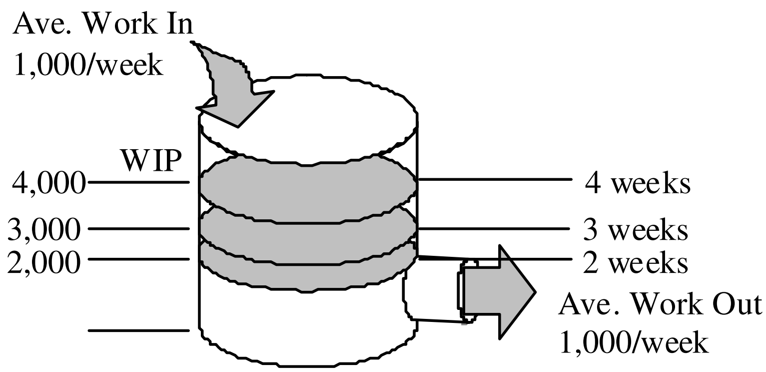


WIP, Lead Time & Service Level ..



Optimising Equipment Maintenance

WIP, Lead Time & Service Level ..



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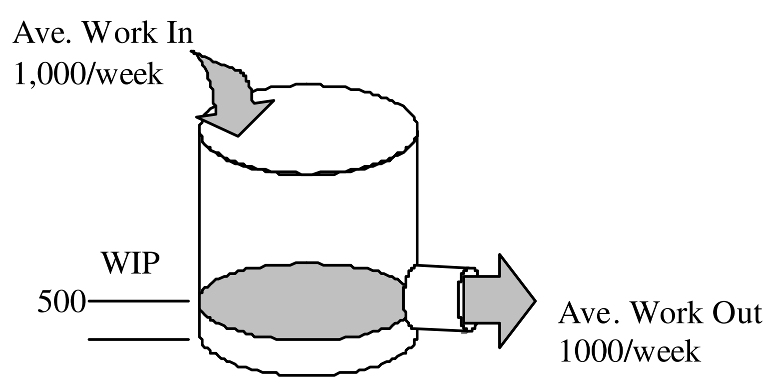
Optimising Equipment Maintenance

What happens if level is 500 ?



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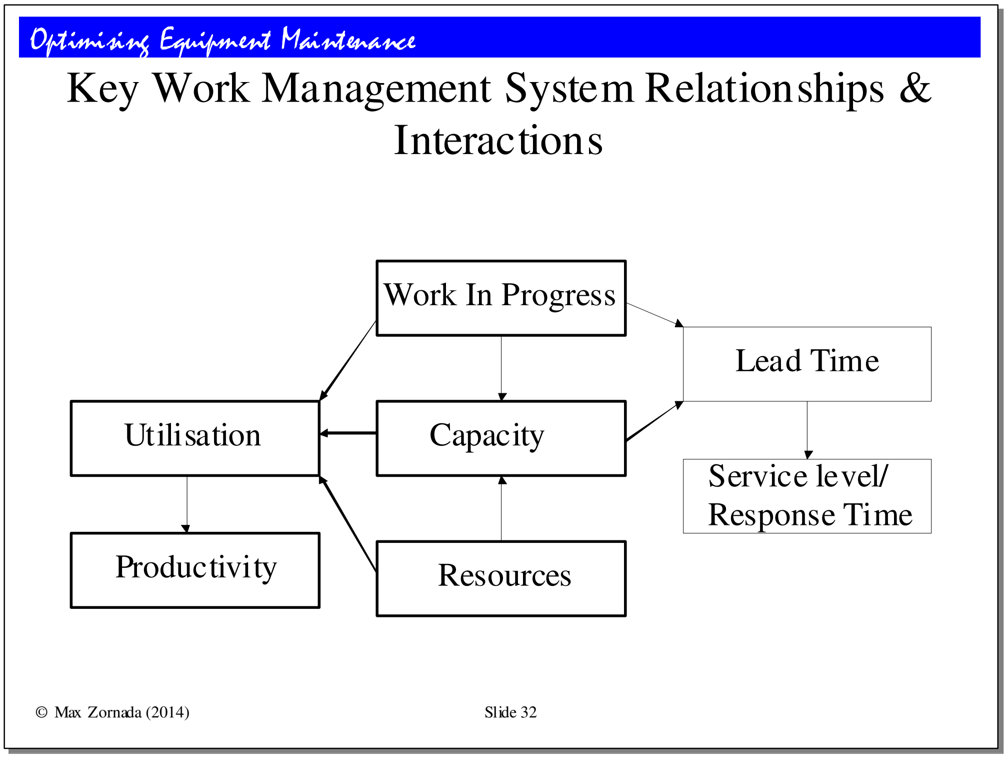
Optimising Equipment Maintenance
Key Work Management System Relationships & Interactions
Work In Progress
Lead Time
Utilisation
Capacity
Service level/
Response Time
Productivity
Resources
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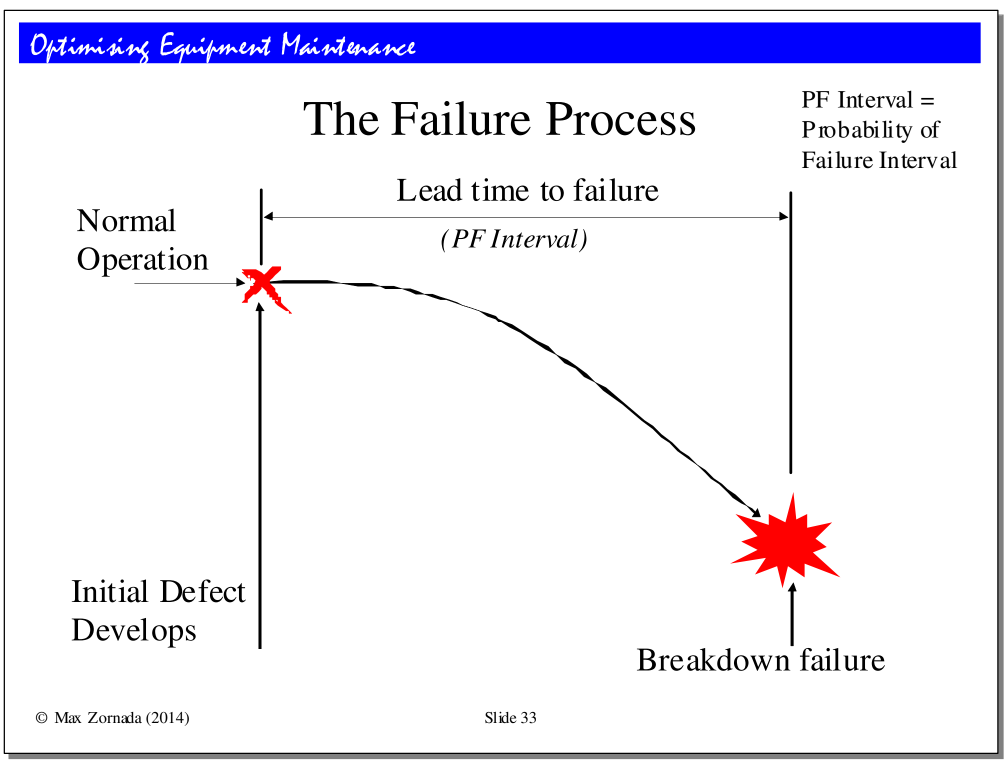
Optimising Equipment Maintenance
The Failure Process
PF Interval =
Probability of
Failure Interval
Lead time to failure
(PF Interval)
Normal
Operation
Initial Defect
Develops
Breakdown failure
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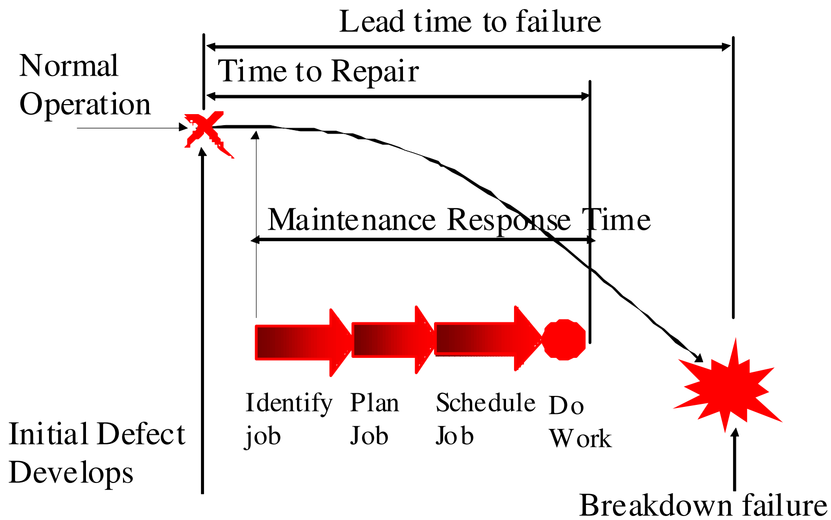
Optimising Equipment Maintenance

Time to Repair & Maintenance Response



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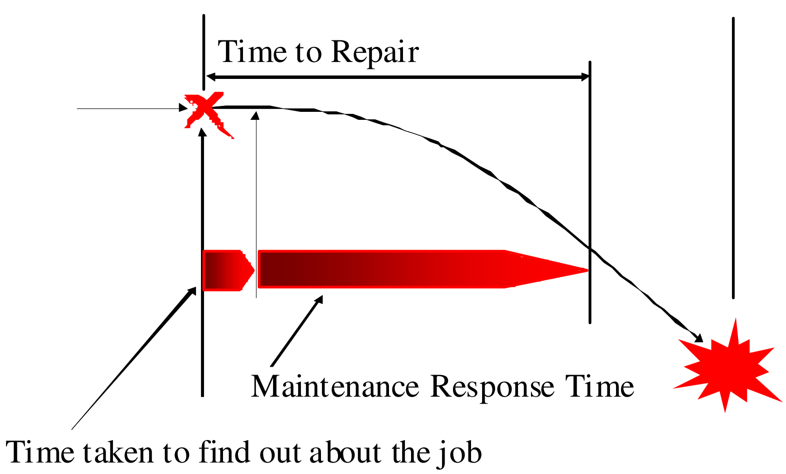
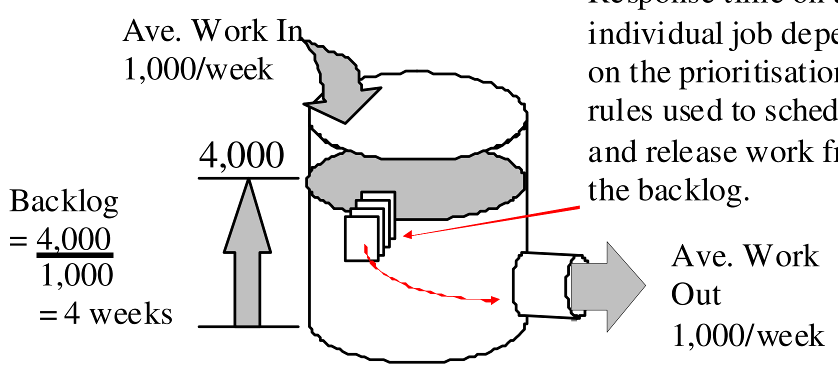
Factors Determining Time to Repair



Average Maintenance Response is determined by the level of backlog ..



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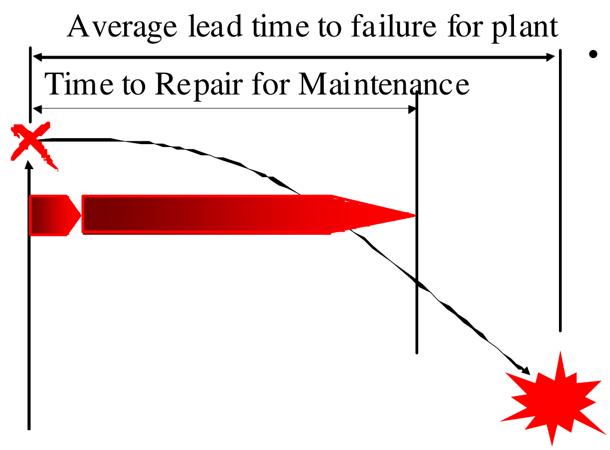
Planning and Scheduling driven maintenance



- If backlog level is kept at a level such that lead time to repair is <u>less than</u> average lead time to failure, then most maintenance work will be planned and scheduled in an orderly manner and high % planned and % scheduled work are possible.

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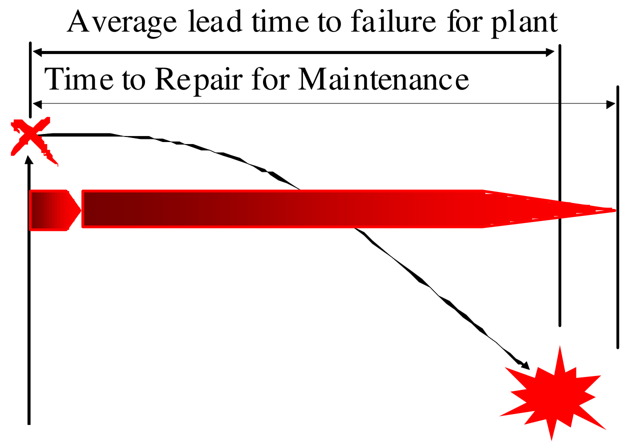
Optimising Equipment Maintenance

Breakdown maintenance

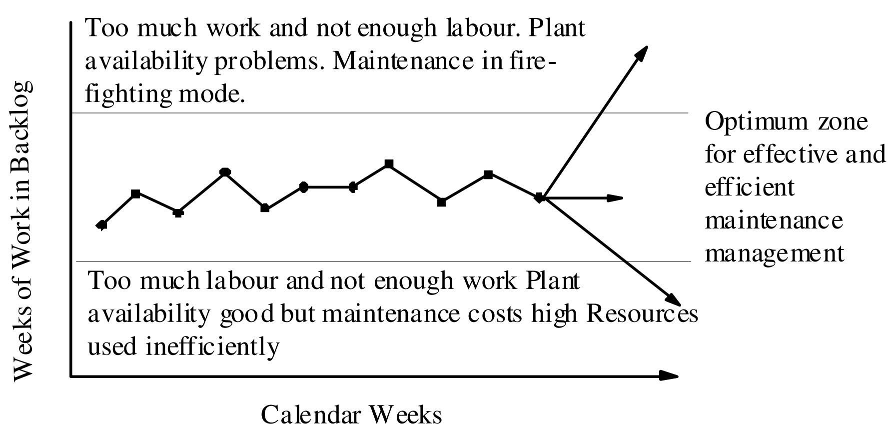


- If backlog level is allowed to get high enough that lead time to repair is <u>greater than</u> average lead time to failure, then most maintenance work will be driven by responding to breakdowns and emergencies.

Optimising Equipment Maintenance

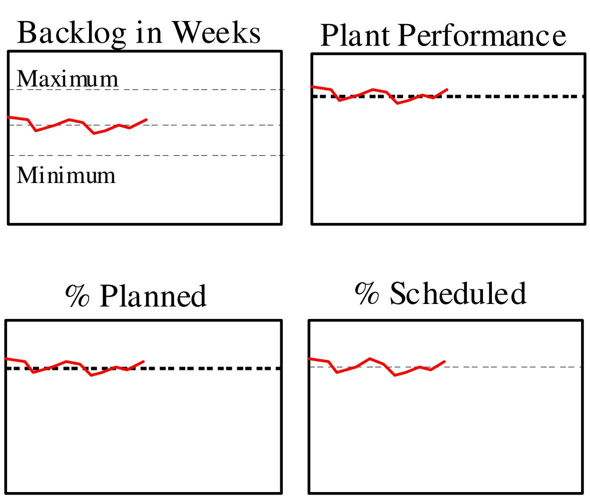
Managing Maintenance Backlogs

Determining the optimum level required to achieve business objectives:-



Lead and Lag Indicators for Maintenance Management and Reliability

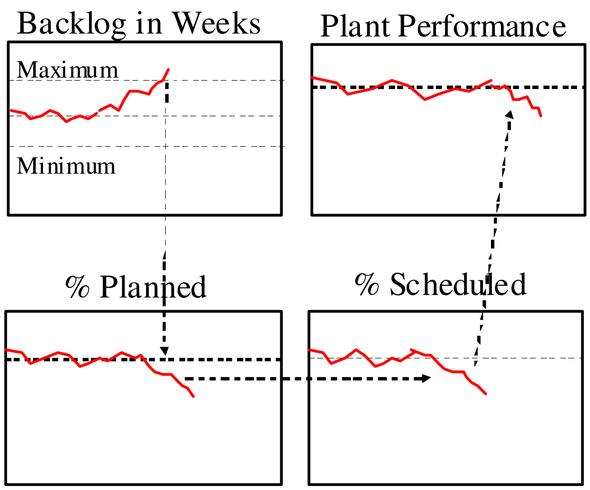
Monitoring Maintenance Management KPI's



- Backlog held at optimal level gives good plant performance.
- High levels of planned and scheduled work achievable

Optimising Equipment Maintenance

Monitoring Maintenance Management KPI's

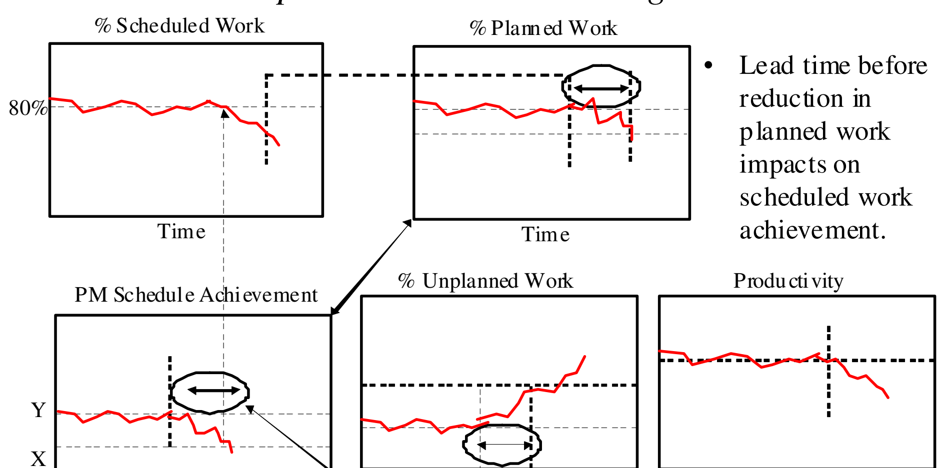


- Backlog get to high;
- Breakdowns interrupt schedule, leading to % schedule reducing;
- Leads to less planned work done;
- Leads to deterioration in plan performance.

Optimising Equipment Maintenance

Outcomes vs. Leading Indicators

Example: Maintenance Management



- Lead time before reduction in planned work impacts on scheduled work achievement.

- Lead time before impact felt on scheduled work

Overall Equipment Effectiveness

Also called: Overall Asset Effectiveness

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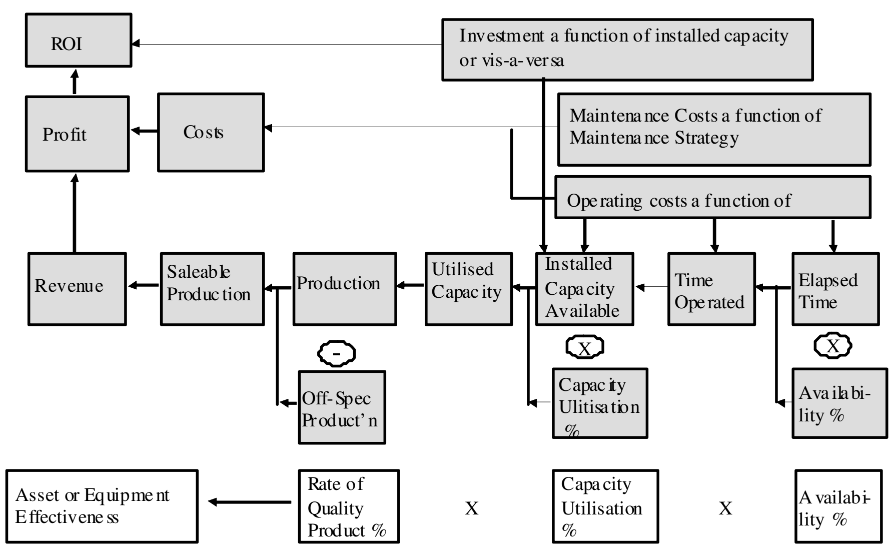
Optimising Equipment Maintenance

Asset Effectiveness



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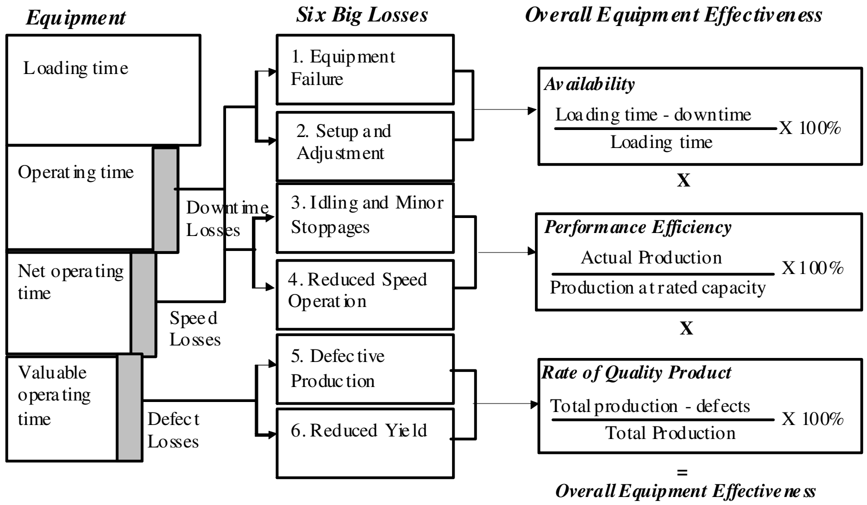
Equipment & Asset Effectiveness

Linking Asset Performance to "Bottomline" Performance



Ref: Seiichi Nakajima (1971)

OEE Definition

The objective of OEE is to evaluate the global effectiveness of a specific equipment of plant. It is calculated considering losses of Availability, Productivity and Quality.

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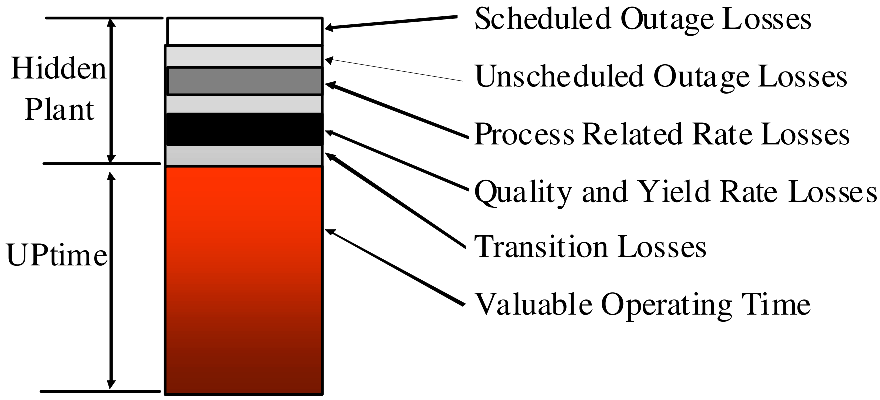
Process Industry Equivalent of OEE: UPtime

the equivalent amount of time the facility can operate at its maximum demonstrated rate while making first quality product.



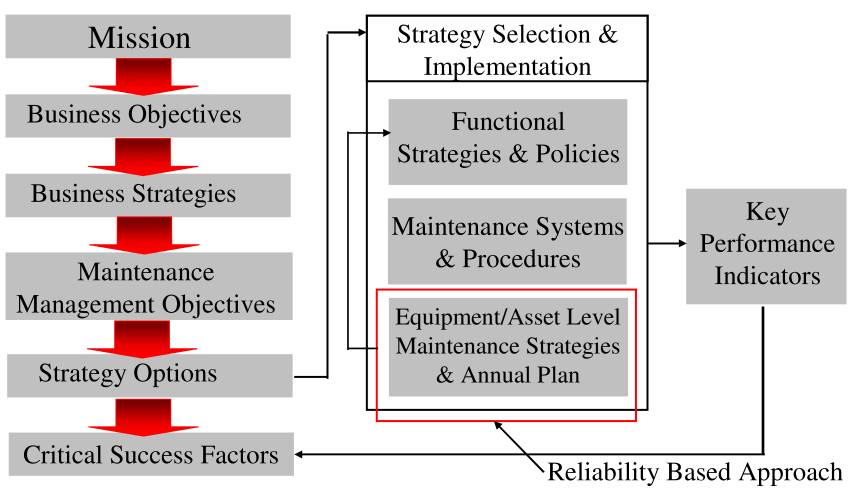
Module 2:

Preventive Maintenance and Spare Parts Strategy

Reliability Based Preventive Maintenance Strategy

 Slide 1

A Strategic Approach to Maintenance Management



 Slide 2

Optimising Equipment Maintenance

Introduction to Reliability Centred Maintenance (RCM)

Slide 3

Optimising Equipment Maintenance

The Purpose of RCM

- RCM determines what must be done to ensure that any physical asset continues to fulfill its intended functions in its present operating context

Slide 4

Optimising Equipment Maintenance

The 7 Questions of RCM

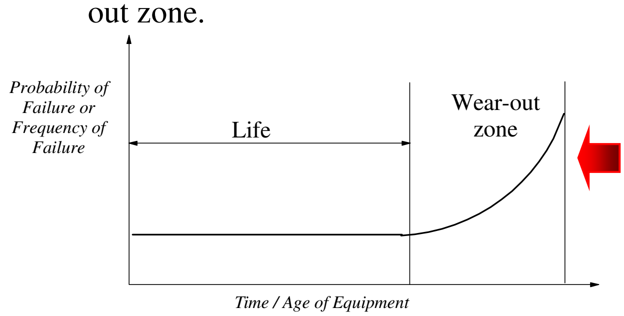
- What are the functions and the required performance standards of the asset?
- In what ways does it fail to fulfil its functions?
- What causes each functional failure?
- What happens when each failure occurs?
- In what way does each failure matter?
- What can be done to prevent each failure?
- What should be done if a suitable preventive task cannot be found?

 Slide 5

Optimising Equipment Maintenance

Traditional Views of Equipment Failure

- The frequency of scheduled restoration (PM/Overhauls) and/or scheduled discard (replacement) is determined by the equipment life;
- Carry out PM or replace just before reaching the wear-out zone.

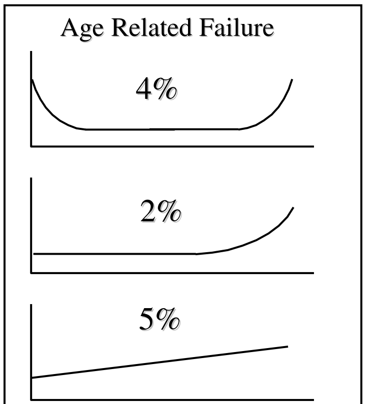


Traditional overhaul and time based preventive maintenance assumes that this is true. Its not!

 Slide 6

What the Research says about Equipment Failure

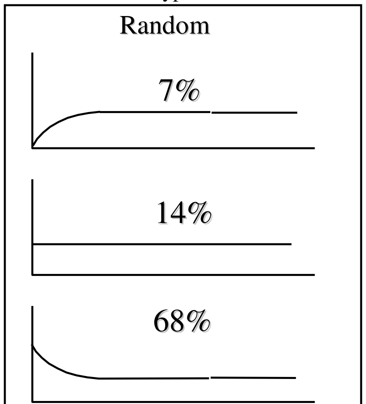
Wear out curves with potential benefit from overhaul type/time based PM



Usually applies to simple items or when there is a dominant failure mode

8%-23% of equipment is like this.

Wear out curves with no potential benefit from overhaul type/time based PM



Usually applies to complex equipment such as electronics, hydraulics and pneumatics

77%to 92% of equipment is like this.

Ref: Statistics courtesy of Navair

Evolution of Maintenance Technologies

1930

Breakdown Maintenance I.e. Maintain on Failure

1950

- Preventive Maintenance Systems
- Planned maintenance

1980

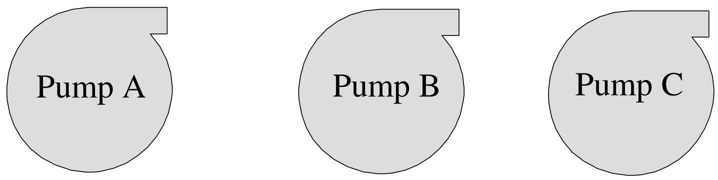
- Computerised Maintenance Management
- Planning and Scheduling
- Backlog Management

1990 2000

- RCM
- TPM
- FMECA
- Risk Based Maintenance
- RAM
- Proactive Maintenance
- CM

Consider 3 identical pumps

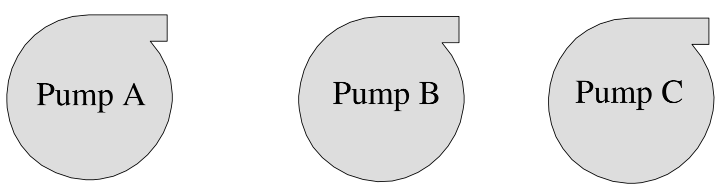
What is the best Preventive Maintenance Program?



- ❖ Fixed time maintenance?
- ❖ Condition monitoring?
- ❖ Run to failure?

The Operating Context influences PM

Three Items of Equipment Three PM Approaches



Stand-alone	Common Spare	Stand-by
Operational Consequences	Non-Operational Consequences	Hidden Failure
❖ Overhauls ❖ Fixed time inspections ❖ Condition monitoring	❖ No scheduled maintenance	❖ Check for failure

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Reliability Centred Maintenance

- Developed within the US aircraft industry to provide a formal definition of preventive maintenance tasks in a safety critical environment;
- Based on reliability engineering principles and focuses maintenance on expected failure modes within a specific operating context.

Impact of RCM on Work Loads

- Reduced overhaul scope of work:
  – DC8:339 Items - DC10:Only 7 Items
- Reduced Effort
  – 20,000 hour major overhaul
  – DC8: 4 Million manhours
  – 747 : 66,000 manhours

Optimising Equipment Maintenance

Impact of RCM on Safety

- Overall Fatality Rates
  - 1958: 60 per million takeoffs
  - 1998: 1 per million takeoffs
- Equipment Failure as a Root Cause
  - 1958: 40 per million takeoffs (2/3)
  - 1998: 1 in 30 million takeoffs (1/1200 of the historical rate)

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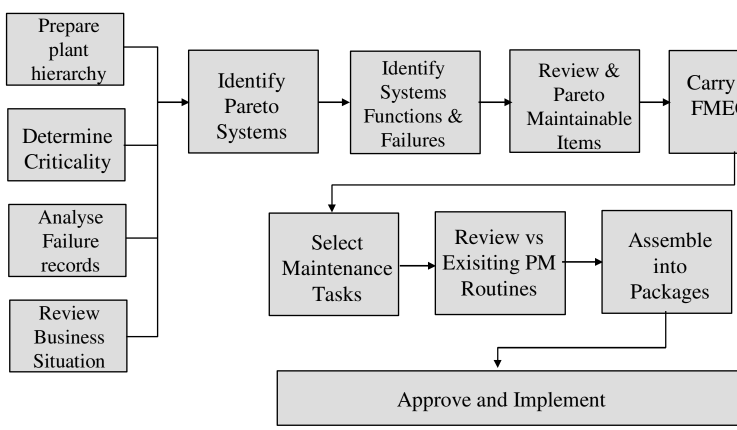
Optimising Equipment Maintenance

Reliability Based Approach to Maintenance Strategy



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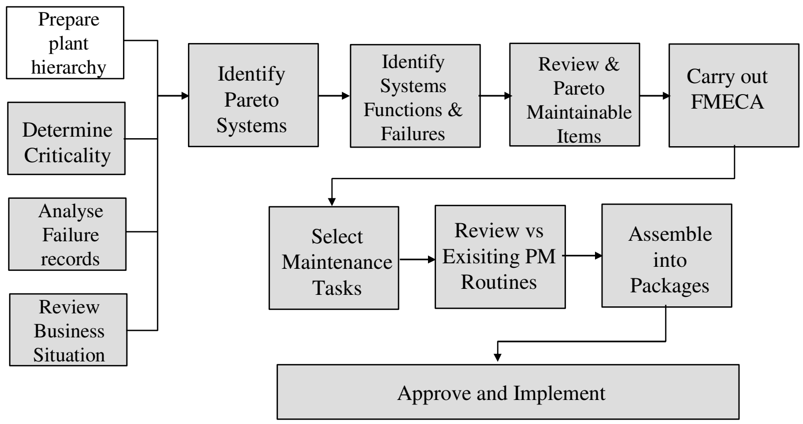
Optimising Equipment Maintenance

Reliability Based Approach to Maintenance Strategy



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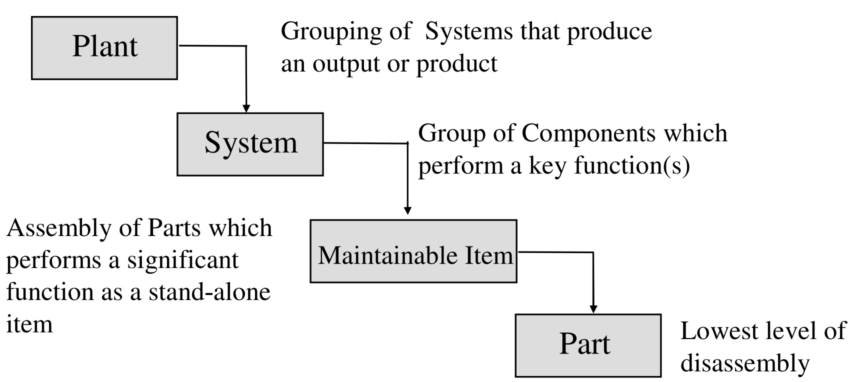
Optimising Equipment Maintenance

Suggested Plant Hierarchy



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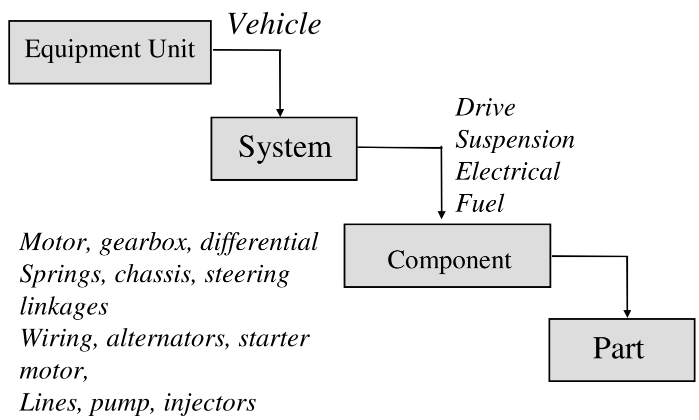
A Example of an Equipment Hierarchy

A system ceases to function because a maintainable item does not operate because a part fails:-



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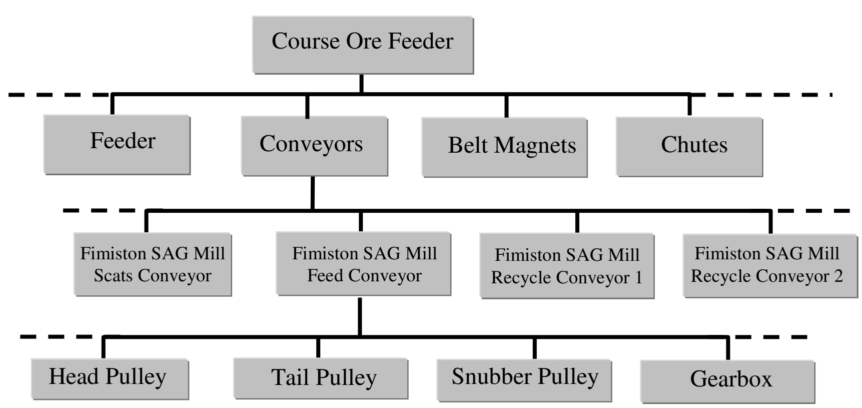
Optimising Equipment Maintenance

Plant Hierarchy Example



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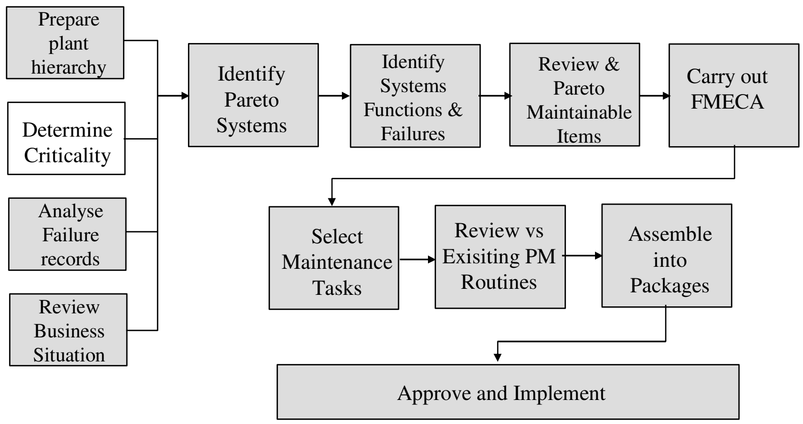
Reliability Based Approach to Maintenance Strategy



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Definition of Criticality

- Criticality is the impact of failure of a system or maintainable item on:
  - Environment;
  - Safety;
  - Plant integrity;
  - Sales and customers;
  - Production (and sales);

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The Use of Criticality

- Criticality is used to determine the order in which we will address the systems/maintainable items. Having selected a system, criticality is not used in the analysis in determining what is the appropriate maintenance strategy, which, as we shall see, has more to do with cost and other matters. However at the maintainable item level criticality or some other measure may be used to determine whether or not to spend the time developing the strategy or not.
- Again depending on the reason for carrying out RCM criticality may not have any bearing on our decisions. For instance if the purpose was to reduce plant downtime caused by maintenance problems and there were adequate records indicating which items of plant were the main offenders, then these records could be used for setting the priority in which the systems / components were addressed.

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An Example of Criticality Definitions

Criticality 1

- Immediate or severe danger to personnel
- Major production stoppage
- Major quality impact
- Immediate or severe danger to environment

Criticality 2

- Potential safety or environmental hazard
- Minor production stoppage
- Minor quality impact
- No back-up

Criticality 3

- Increased risk of production or quality loss

Criticality 4

- No identifiable or likely production or quality impact

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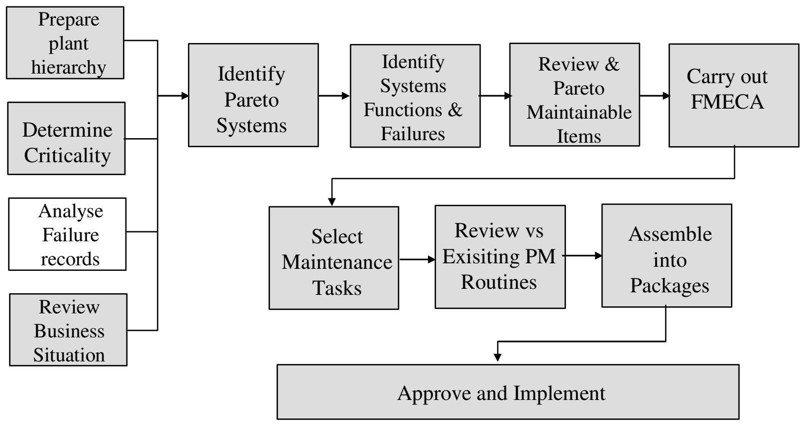
Reliability Based Approach to Maintenance Strategy



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Optimising Equipment Maintenance

Analyse Failure Records

- Need to establish starting measures of Reliability;
- Need to analyse downtime if it is the driver of the project:
  - Total downtime by plant/system;
  - Frequency of failure (MTBF or FR);
  - Average duration of downtime (MTTR);
- Need to analyse maintenance costs.

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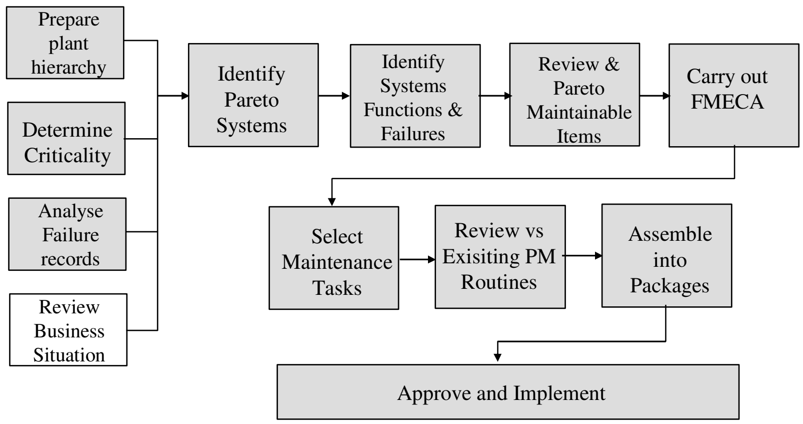
Optimising Equipment Maintenance

Reliability Based Approach to Maintenance Strategy



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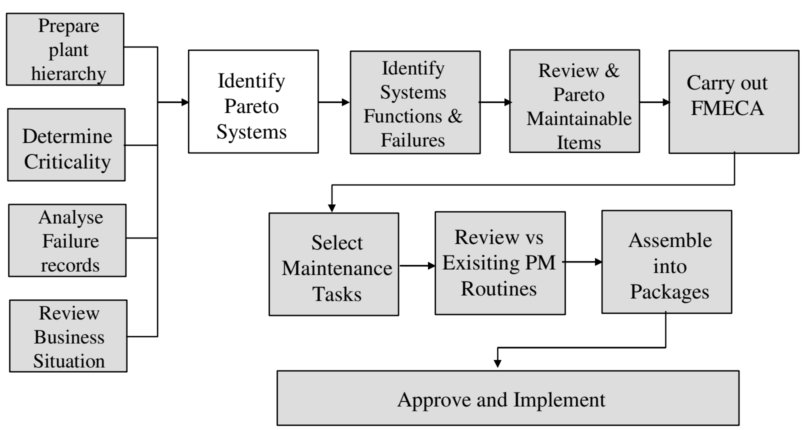
Reliability Based Approach to Maintenance Strategy



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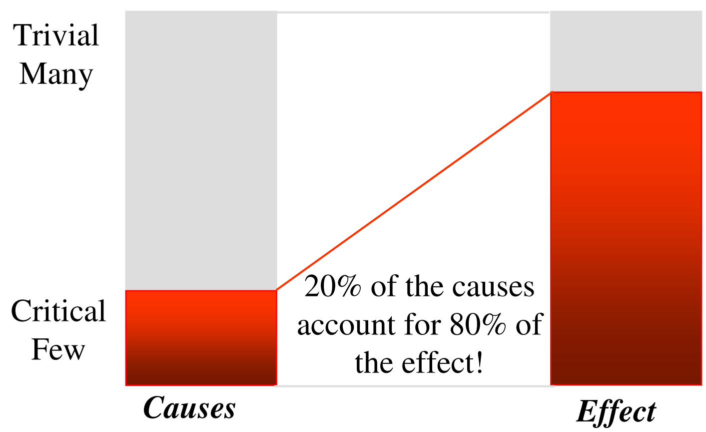
Optimising Equipment Maintenance

Pareto Analysis

The Pareto Principle (The 80/20 Rule):
"A few causes account for most of the effect"



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Optimising Equipment Maintenance

Determine Order of Systems on which to apply the RCM Process

- Determine Order of Systems on which to apply the RCM Process;
- Identify the driver (business reason) establishing the priority of a system;
- Rank maintainable items in descending order of importance.

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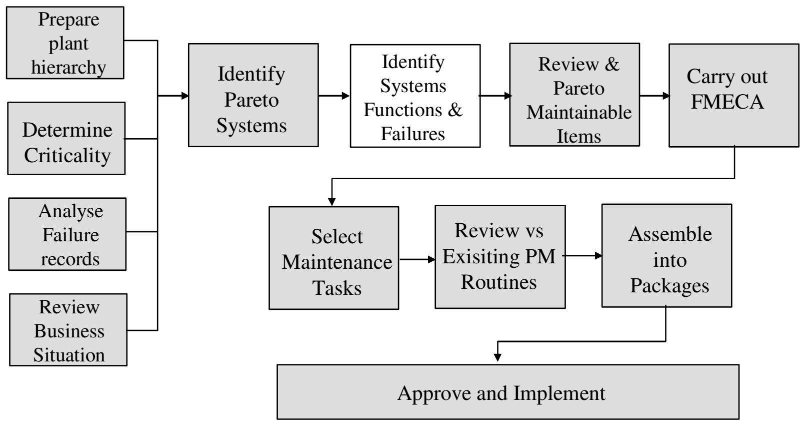
Reliability Based Approach to Maintenance Strategy



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Optimising Equipment Maintenance

Define System Functions and Failure Types

- For each selected System:
  - describe the system its mode of operation and required functions;
  - define the various ways in which the system can fail to perform its function (assume appropriate supply of inputs i.e. required outputs from other systems are being provided);
  - analyse existing records or knowledge to determine how the components have failed historically.

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Optimising Equipment Maintenance

RCM Analysis - Function and Functional Failure

Unit :	
System :	
System Function	Functional Failure

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Optimising Equipment Maintenance

RCM Analysis - Function and Functional Failure

Unit : *Crude Stabilisation Plant*	
System : *Reboiler System*	
System Function	Functional Failure
1. Heat Crude Oil to achieve specified	*1.1 No temperature increase achieved*
temperature increase.	*1.2. Temperature increase less than specification*
	1.3. Temperature increase more than specification
2. Circulate Oil at specified flowrate.	*2.1 No flow*
	2.2. Flow less than specification
	2.3. Flow more than specification
3. Maintain separation between steam side	*3.1 Oil leak into steam condensate system*
and oil side to avoid cross contamination.	*3.2 Steam leak into oil side*
4. Hold process pressure on oil side.	*4.1. Oil leak to atmosphere*
5. Hold process pressure on steam side.	*5.1. Steam leak to atmosphere*
6. …. ??	

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Optimising Equipment Maintenance

Functions and Failures

- **Functions:** - How does it work and what performance do we want from the equipment in its present operating context?
- **Functional Failures:** - In what way does it fail to do what we want?
- **Failure Modes:** - What actually causes each failure?
- **Failure Effects:** - What happens when each failure mode occurs?

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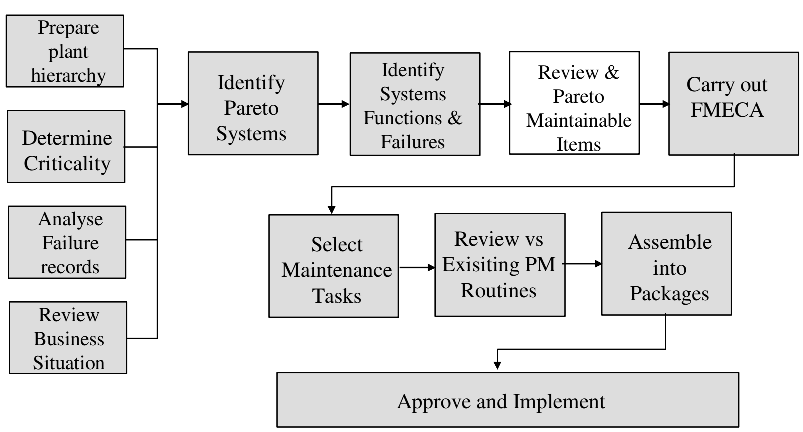
Optimising Equipment Maintenance

Reliability Based Approach to Maintenance Strategy



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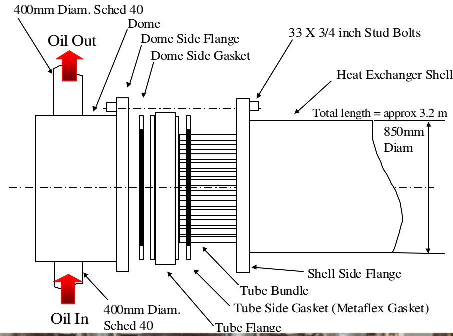
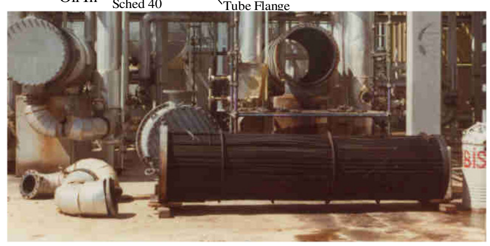
Optimising Equipment Maintenance

Review & Pareto Maintainable Items

- analyse historical failures
- imagine how failures may happen
- consider the impact of existing preventive maintenance routines





Optimising Equipment Maintenance

RCM Analysis - Maintainable Item and Functional Failure Table

Unit : *Crude Stabilisation Plant*

System : *Reboiler System*

Maintainable Item / Functional Failure	*1.1 No temperature increase achieved*	*1.2. Temperature increase less than specification*	*1.3. Temperature increase more than specification*	*2.1 No flow*	*2.2. Flow less than specification*	*2.3. Flow more than specification*	*3.1 Oil leak into steam condensate system*	*3.2 Steam leak into oil side*	*4.1. Oil leak to atmosphere*	*5.1. Steam leak to atmosphere*
1. Heat exchanger unit	X									
2. Reboiler Pump		X		X	X					
3. Reboiler Pump Motor				X						
4. Steam Flow Control Valve	X	X	X							
5. Oil Flow Control Valve			X	X	X	X				
6. ……..										

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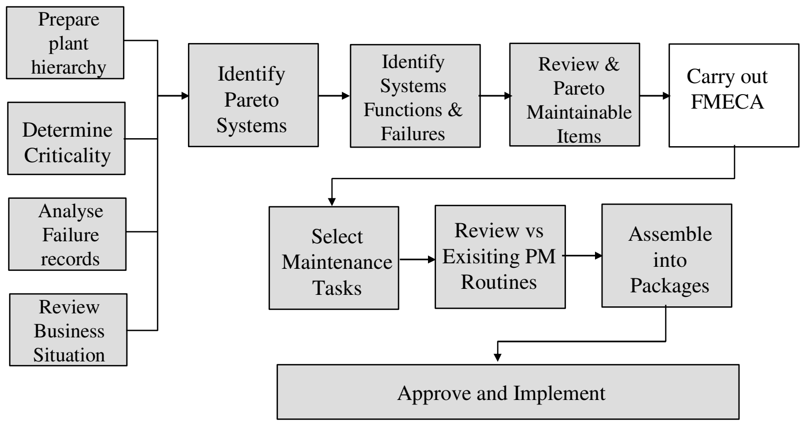
Reliability Based Approach to Maintenance Strategy



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Optimising Equipment Maintenance

Failure Modes, Effects & Consequences Analysis (FMECA)

- FMECA refers to the determination of functions, functional failures, failure modes, failure effects, and failure rates to the extent required for RCM analysis of a selected item.
- Does not intend to imply that a full FMEA or FMECA as defined for design or other processes is required to perform RCM…

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Failure Modes, Effects & Consequences Analysis (FMECA)

- Select maintainable items most likely to fail
- For each identified maintainable item, determine all the failure modes
- For each failure mode identify root cause and the consequence of the failure
- Apply a ranking to each mode of failure considering impact on :
  - safety
  - regulations
  - product quality

Failure Consequences or Effects

- **Hidden Failures:** -Mostly protective devices which are not fail-safe.
- **Safety or Environmental Consequences:** -Some-one could get hurt or killed, or an environmental standard or regulation could be breached.
- **Operational:-** Affect output, product quality or customer service.
- **Non-operational Consequences**: - Repair only.

Optimising Equipment Maintenance

RCM Analysis - Failure Modes and Effects Analysis

Unit:

System:

Function	Functional Failure	Failure Mode	Failure Effect	Criticality	Response

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Optimising Equipment Maintenance

RCM Analysis - Failure Modes and Effects Analysis

Unit:

System:

Function	Functional Failure	Failure Mode	Failure Effect	Criticality	Response

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RCM Analysis - Failure Modes and Effects Analysis

Unit:

System:

Function	Functional Failure	Failure Mode	Failure Effect	Criticality	Response

What happens when this failure mode occurs?

What caused it to fail?

How serious is it?

In what ways can it fail to do this?

What can we do about it?

What does it do ?

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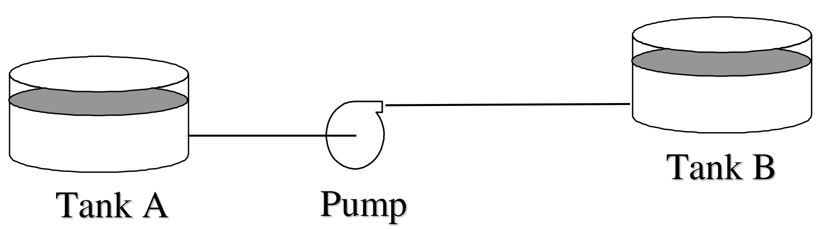
Consider a simple system such as



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Optimising Equipment Maintenance

Analysing the Functions and Failures

	Function		Functional Failure		Failure Mode (Cause of Failure)	Failure Effect (What Happens After it Fails)
1	*To pump water from Tank A to Tank B at not less than 1000 Litres per minute*	A	*Fails to pump any water at all.*	1	*Bearing seized*	*Motor trips, trip alarm sounds. Tank B low level alarm sounds after 20 minutes and tank runs dry in 30 minutes. Downtime to replace bearing about 4 hours.*
				2	*Coupling fails*	*Motor does not trip but low level alarm sounds after 20 minutes. Downtime to replace coupling about 3 hours.*
				3	*etc., etc., ...*	
		B	*Pumps less than 1,000 litres per min.*	1	*Impeller worn*	*Level in tank B gradually drops until low level alarm sounds. Downtime to replace impeller, about 2 hours.*

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Optimising Equipment Maintenance

RCM Analysis - Failure Modes and Effects Analysis

Unit**:**

System:

Function	Functional Failure	Failure Mode	Failure Effect	Criticality	Response

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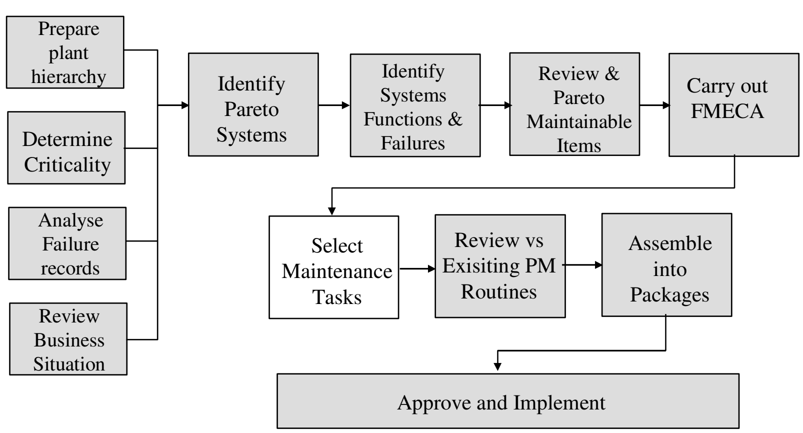
Optimising Equipment Maintenance

Assessing Criticality

Likelihood		Risk Financial Impact	$0 - $500	$500 - $1k	$1 - 5K	$5k - $10k	$10k - $50k	$50k - $100k	$100k - $500k	$500k - $1M	$1M - $5M	$5M - $10M	$10M - $50M	$50M - $100M	$100M - $500M	>$500M
		Concenquence	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	14	More than once per day	1.00	1.70	2.89	4.92	8.38	14.25	24.24	41.25	70.17	119.38	203.09	345.51	587.80	1,000.00
	13	Daily	0.70	1.19	2.03	3.46	5.88	10.00	17.01	28.94	49.24	83.77	142.51	242.45	412.46	701.70
	12	1 per week	0.49	0.84	1.43	2.42	4.12	7.02	11.94	20.31	34.55	58.78	100.00	170.13	289.43	492.39
	11	fortnight event	0.35	0.59	1.00	1.70	2.89	4.92	8.38	14.25	24.24	41.25	70.17	119.38	203.09	345.51
	10	One per month	0.24	0.41	0.70	1.19	2.03	3.46	5.88	10.00	17.01	28.94	49.24	83.77	142.51	242.45
	9	One per quarter	0.17	0.29	0.49	0.84	1.43	2.42	4.12	7.02	11.94	20.31	34.55	58.78	100.00	170.13
	8	One each 6 months	0.12	0.20	0.35	0.59	1.00	1.70	2.89	4.92	8.38	14.25	24.24	41.25	70.17	119.38
	7	One per Year	0.08	0.14	0.24	0.41	0.70	1.19	2.03	3.46	5.88	10.00	17.01	28.94	49.24	83.77
	6	One in 3 years	0.06	0.10	0.17	0.29	0.49	0.84	1.43	2.42	4.12	7.02	11.94	20.31	34.55	58.78
	5	One in 5 years	0.04	0.07	0.12	0.20	0.35	0.59	1.00	1.70	2.89	4.92	8.38	14.25	24.24	41.25
	4	One in 10 years	0.03	0.05	0.08	0.14	0.24	0.41	0.70	1.19	2.03	3.46	5.88	10.00	17.01	28.94
	3	One in 20 years	0.02	0.03	0.06	0.10	0.17	0.29	0.49	0.84	1.43	2.42	4.12	7.02	11.94	20.31
	2	One in 50 years	0.01	0.02	0.04	0.07	0.12	0.20	0.35	0.59	1.00	1.70	2.89	4.92	8.38	14.25
	1	One in more than 100 years	0.01	0.02	0.03	0.05	0.08	0.14	0.24	0.41	0.70	1.19	2.03	3.46	5.88	10.00

Optimising Equipment Maintenance

Reliability Based Approach to Maintenance Strategy



Preventive Maintenance Task Options

- S (Servicing Task) - Replenishment of consumable materials depleted during normal operations
- L (Lubrication Task) - Replacement of a lubricant based on manufacturer's predicted or measured life of the lubricant
- OC (On Condition Task) - Periodic or continuous inspection designed to detect a potential failure condition prior to functional failure
- ST (Time Scheduled Task)
  - STR - Scheduled restoration - overhaul at fixed intervals regardless of its condition;
  - STD - Scheduled discard - replace at fixed intervals regardless of its condition.
- FF (Failure Finding Task) - A preventive maintenance task performed at a specified interval to determine whether a hidden functional failure has occurred.

Optimising Equipment Maintenance

Other Actions

- One time action, other than PM, that will effectively reduce the likelihood and consequences of failure to an acceptable level
  - Redesign - change the equipment or the process;
  - Change in an operational or maintenance procedure
  - Operating restrictions
- Failure - check finds that failure has occurred;
- No scheduled maintenance.

Optimising Equipment Maintenance

Select Maintenance Task

– Apply the Task Selection Decision Tree logic
– Determine the specific maintenance task/action
– For each maintenance task carry out preliminary planning. Determine :
  – task frequency
  – skill classification
  – labour duration and numbers

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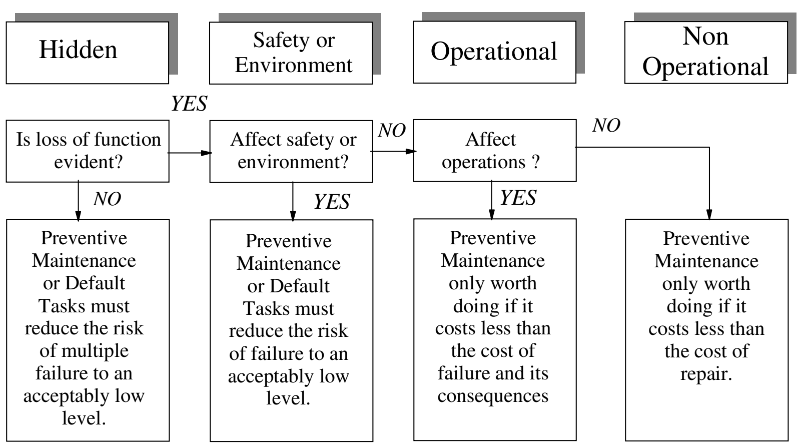
Optimising Equipment Maintenance

Maintenance Policies



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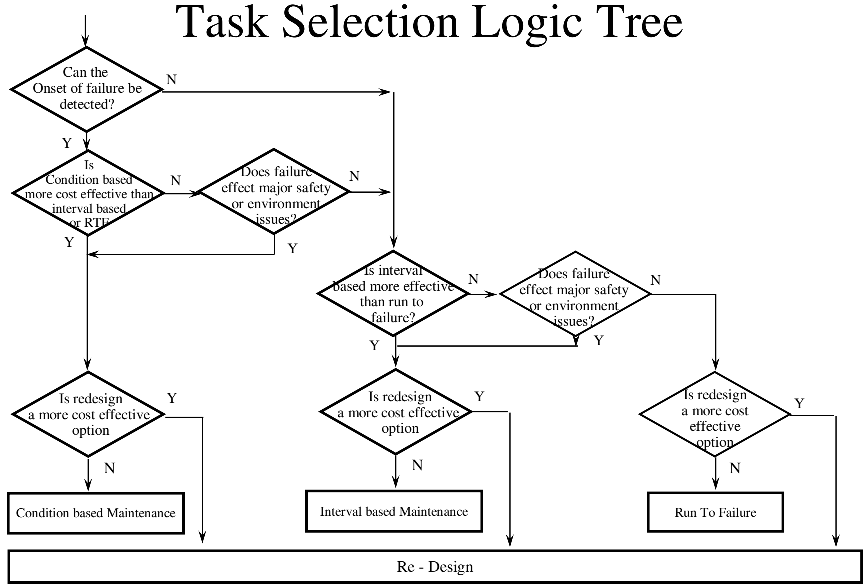
Optimising Equipment Maintenance

Task Selection Logic Tree



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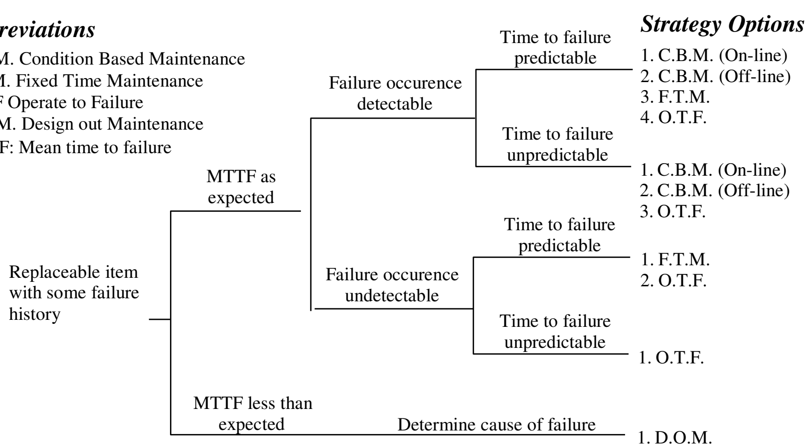
Optimising Equipment Maintenance

Determining the Optimum Maintenance Strategy

Traditional Preventive Maintenance based approaches do not always work:-

Abbreviations

C.B.M. Condition Based Maintenance
F.T.M. Fixed Time Maintenance
O.T.F Operate to Failure
D.O.M. Design out Maintenance
MTTF: Mean time to failure



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Optimising Equipment Maintenance

Reliability Based Maintenance Strategy Chart

	Criticality 1				Criticality 2				Criticality 3				Criticality 4			
	Total product lost irretrievably Major Safety/Environmental Impact				Partial Production loss or loss of efficiency. Major Environmental Impact				Increased risk of production or efficiency loss. (Spared equip, by pass control valves etc.)				No Impact on Production			
Differential Maintenance Cost of Failure	High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)	
Failure Predictable	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Type of Maintenance																
Inspection/Lubrication	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Preventive Maintenance (Task)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	N
Condition Monitoring	Y	N	Y	N	Y	N	Y	N	Y	N	N	N	N	N	N	N
Change Out On Life	N	Y	N	Y	N	Y	N	N	N	Y	N	N	Y	Y	N	N
Run to Failure	N	N	N	N	N	N	N	Y	N	N	Y	Y	N	N	Y	Y
Investigation of Breakdowns	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N
Off-Site Repairs (Assuming can be done on site)					To be decided individually											
Use Rotable																

	Criticality 1			Criticality 2			Criticality 3			Criticality 4		
Value of Rotable Stock	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K
Repair Time < 1 Day	Y	Y	Y	N	N	N	N	N	N	N	N	N
1-3 Days	Y	Y	Y	N	N	Y	N	N	N	N	N	N
3-15 Days	Y	Y	Y	Y	Y	Y	N	N	Y	N	N	N
>15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N
Stock Holdings (Items< $20,000) (Whether to Hold Stock or Not)	Assumes no Rotable Stock held for the part											
Value of Total Stock Holding	$2,000 - -$20,000	$500- -$2,000	<$500	$2,000 - -$20,000	$500- -$2,000	<$500	$2,000 - -$20,000	$500- -$2,000	<$500	$2,000 - -$20,000	$500- -$2,000	<$500

	Criticality 1						Criticality 2						Criticality 3						Criticality 4					
Failure Predictable?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Lead Time																								
< 1 Day (Avail Ex. Stock-Local)	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
1-5 Days (Avail Ex. Stock-Country)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N
5-15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N	N	N	N
>15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N

Optimising Equipment Maintenance

Asset Specific Maintenance Strategies

Criticality			
High	Time Based Useful Life, Schedule and Replace Before Failure	Time Based Useful Life, Inspect, PM and CM.	RCM, FMECA, CM, PdM and PM. Root Cause Analysis
Medium	Inspect, Run to Failure	Inspect, Preventive Maintenance.	PM, PdM and Root Cause Analysis
Low	Run to Failure	Operational Maintenance	Preventive Maintenance
Component Value	0-$5,000	$5,000-50,000	$50,000++

Costing Considerations
What are the real costs of failure?

- Lost revenue due to the lost time
- Shut down and start up costs
- Plant ticking over costs
- Off specification product rework costs
- Wasted operator costs
- Additional maintenance administration costs
- Inefficient maintenance working
- Increased inventory
- Consequential damage

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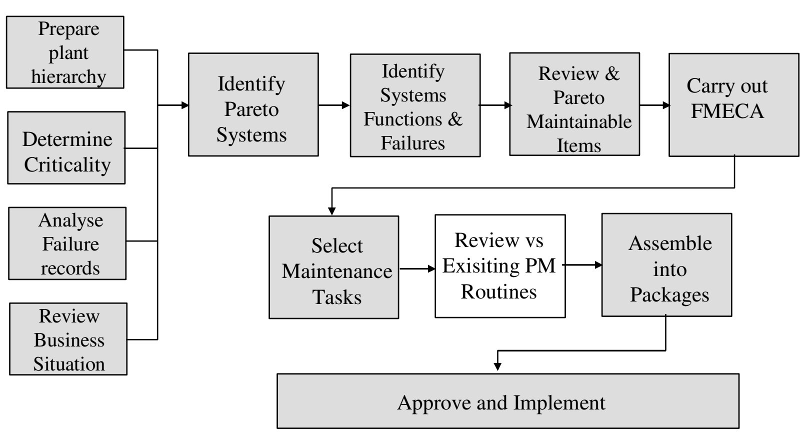
Optimising Equipment Maintenance

Reliability Based Approach to Maintenance Strategy



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Optimising Equipment Maintenance

Review Selected Tasks Against Existing Maintenance Strategy

- Sort tasks by common frequency
- Review existing maintenance programme to :
  - identify any tasks not included in the RCM analysis
  - identify significant differences in frequency and duration of common tasks
- Hold challenge sessions with key maintenance and operating

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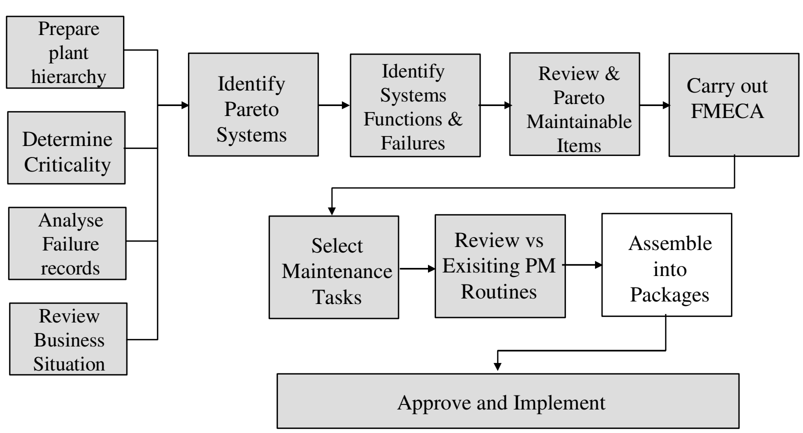
Optimising Equipment Maintenance

Reliability Based Approach to Maintenance Strategy



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Optimising Equipment Maintenance

Assemble Work Packages and Schedule in Computer System

- Complete task planning -Start date, procedure, parts/rotables, access
- Sort tasks into groups with similar skills, access requirements and frequencies
- Assemble grouped tasks into sensible work packages
- Plan the implementation of the new work packages
- Input planned work packages into the maintenance management system

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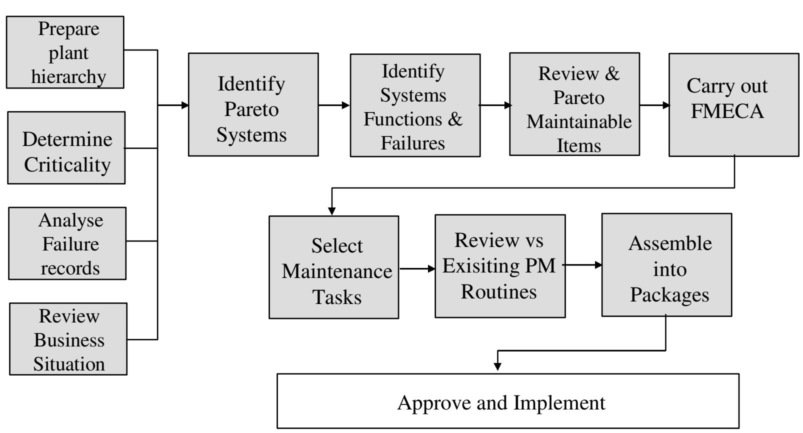
Optimising Equipment Maintenance

Reliability Based Approach to Maintenance Strategy



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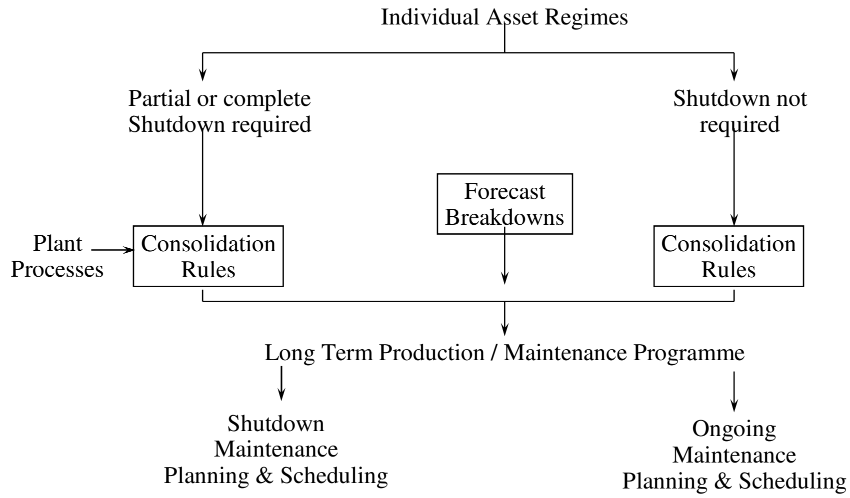
Consolidation of Strategies



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Implementing the RCM Process

- Draw up a plant register;
- Analyse functions and failures;
- Evaluate failure consequences;
- Select maintenance policies;
- Compile maintenance schedules, revise operating procedures, implement design changes;
- Progressively implement into work management system.

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Effect of Using a Reliability Based Approach

Perceived Preventive Maintenance Requirements before applying RCM

→

Preventive Maintenance Requirements after applying RCM

- Reduced by 40% to 70%
- Clearly focused
- More effective

Preventive Maintenance Optimisation

Key Steps in PMO

- Task Compilation - Identify existing maintenance tasks
- Failure Modes Analysis (FMA)
- Rationalisation and FMA review
- Functional Analysis (Optional)
- Consequences Evaluation
- Maintenance Policy Determination
- Group and Review
- Approval and Implementation
- Review and Update in light of operating experience.

Consider all sources of PM

Computerised Maintenance Management Systems

Operator rounds & routines

Condition Monitoring Programs

Contractor Schedules

Memory and Tradition

Vendor Maintenance Manuals

Standard Operating Procedures

Lubrication program

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Step 1 – Task Compilation

Identify Existing Maintenance Tasks

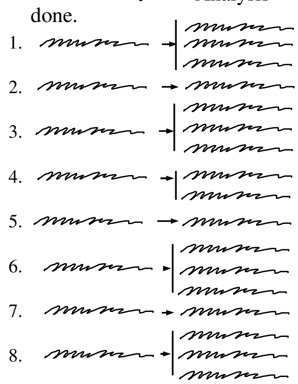
- Identify/collecting or document the existing maintenance program (formal or informal) and load into a database via a spreadsheet.
- Maintenance is often performed by a wide cross section of people including operators.
- Some Preventive Maintenance is done at the initiative of the tradesmen or operators and not documented formally.
- In this situation, task compilation is a simple matter of writing down what the people are doing.

Preventive Maintenance Optimisation

2. Identify the Failure Modes the tasks address

List the Maintenance Tasks already done.

Failure Modes Analysis

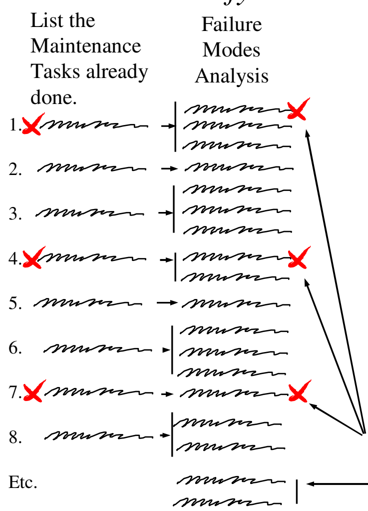


Etc.

Optimising Equipment Maintenance

Preventive Maintenance Optimisation

3. Identify redundant tasks and additional failure modes

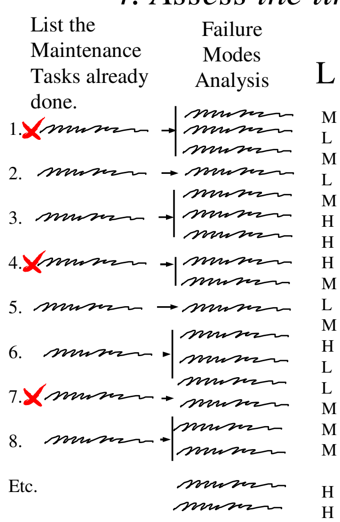


- Redundant tasks arise as a result of
  - different groups performing the same task as part of their routines;
  - the presence of more than one task that address the same failure mode.
- Additional tasks are identified from maintenance history or brainstorming form available information.

Optimising Equipment Maintenance

Preventive Maintenance Optimisation

4. Assess the likelihood of the failure occurring



- Likelihood of frequency rankings:
  - H=High (happens often)
  - M=Medium (happens occasionally)
  - L=Low (rarely or never happens).

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Preventive Maintenance Optimisation

5. Determine the Effects of the Failure Modes

List the Maintenance Tasks already done.

Failure Modes Analysis

L

Failure Effects

1.
2.
3.
4.
5.
6.
7.
8.
Etc.

M
L
M
L
M
H
H
H
M
L
M
H
L
L
M
M
M
H
H

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Optimising Equipment Maintenance

Preventive Maintenance Optimisation

6. Determine if failure effect hidden or evident

List the Maintenance Tasks already done.

Failure Modes Analysis

L

Failure Effects

Type

1.
2.
3.
4.
5.
6.
7.
8.
Etc.

M
L
M
L
M
H
H
H
M
L
M
H
L
L
M
M
M
H
H

E
E
H
H
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H
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H
E
H
H
E
E

Classify the Failure Effect as Evident or Hidden.

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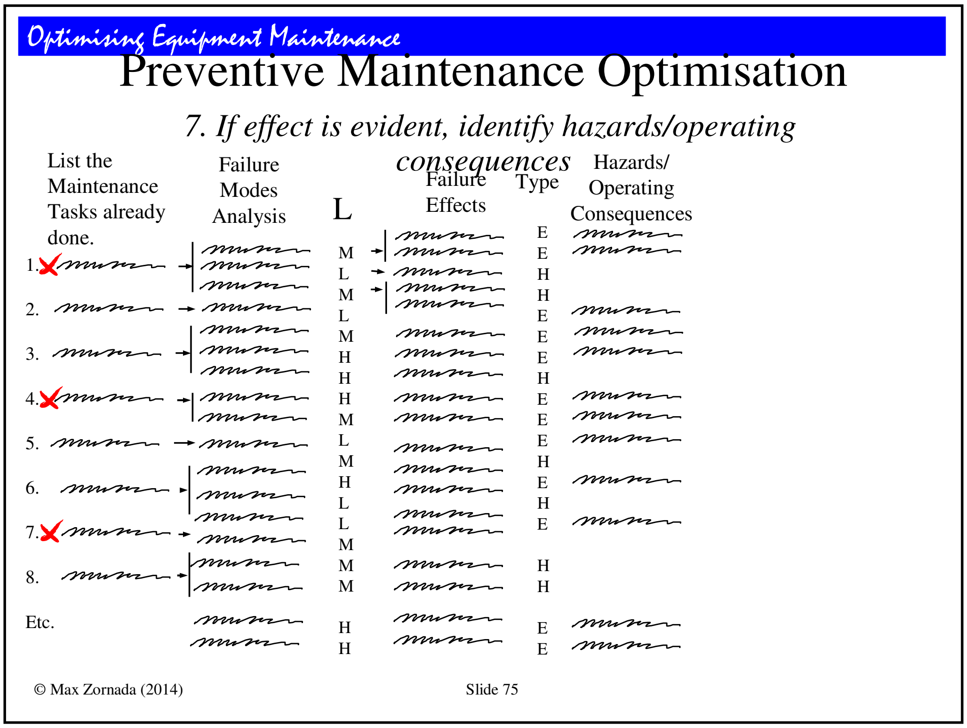
Optimising Equipment Maintenance
Preventive Maintenance Optimisation
7. If effect is evident, identify hazards/operating consequences
List the Maintenance Tasks already done.
Failure Modes Analysis
L
Failure Effects
Type
Hazards/ Operating Consequences
1.
2.
3.
4.
5.
6.
7.
8.
Etc.
M L M L M H H H M L M H L L M M M H H
E E H H E E E H E E E H E H E H H E E
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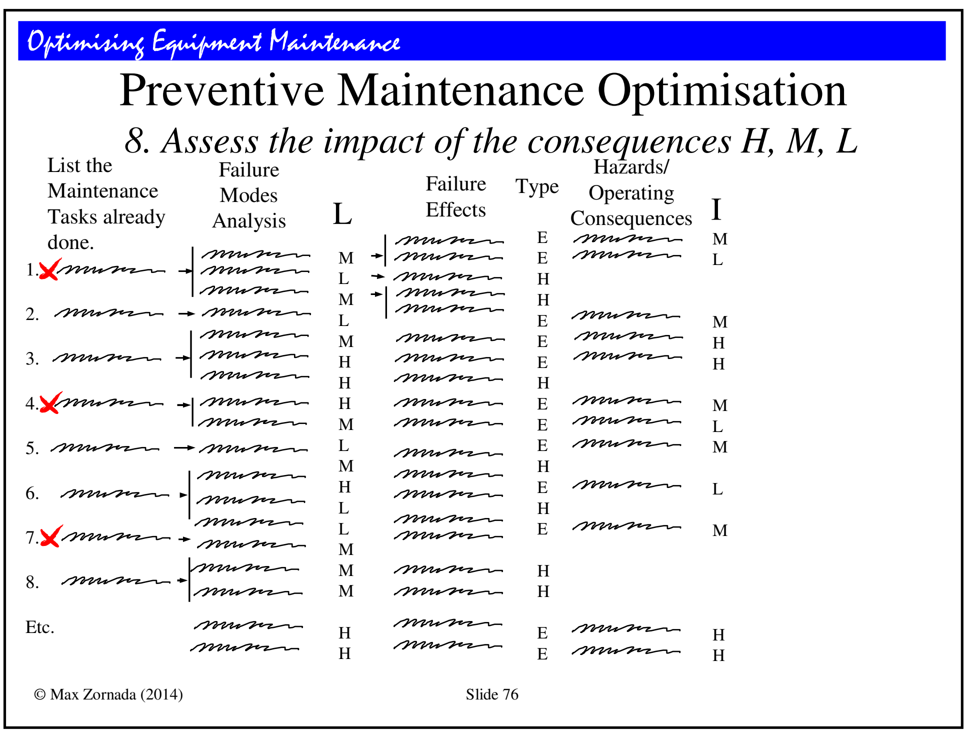
Optimising Equipment Maintenance
Preventive Maintenance Optimisation
8. Assess the impact of the consequences H, M, L
List the Maintenance Tasks already done.
Failure Modes Analysis
L
Failure Effects
Type
Hazards/ Operating Consequences
I
1.
2.
3.
4.
5.
6.
7.
8.
Etc.
M L M L M H H H M L M H L L M M M H H
E E H H E E E H E E E H E H E H H E E
M L M H H M L M L M H H
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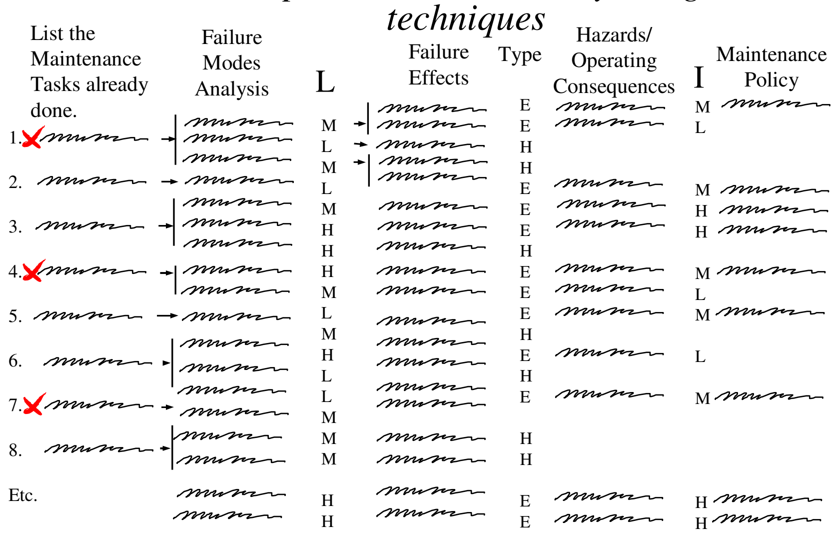
Optimising Equipment Maintenance

Preventive Maintenance Optimisation

9. Develop Maintenance Policy using RCM techniques



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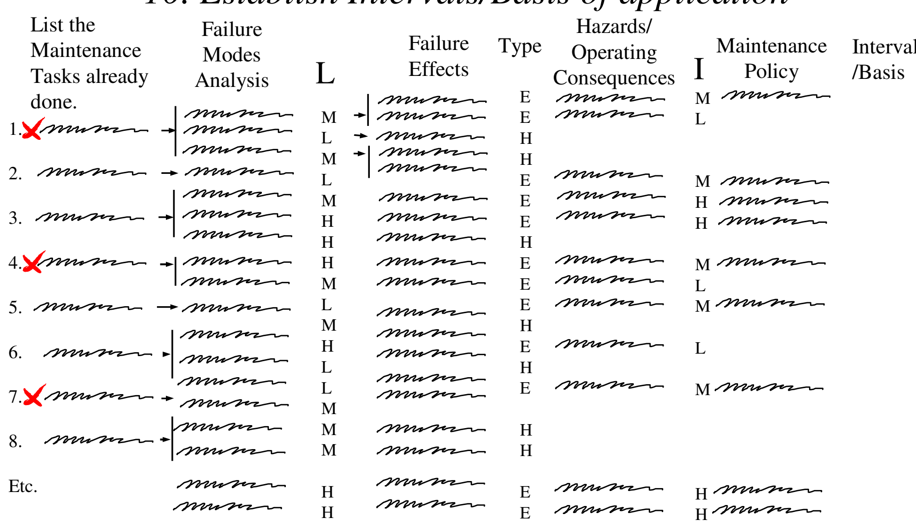
Optimising Equipment Maintenance

Preventive Maintenance Optimisation

10. Establish Intervals/Basis of application



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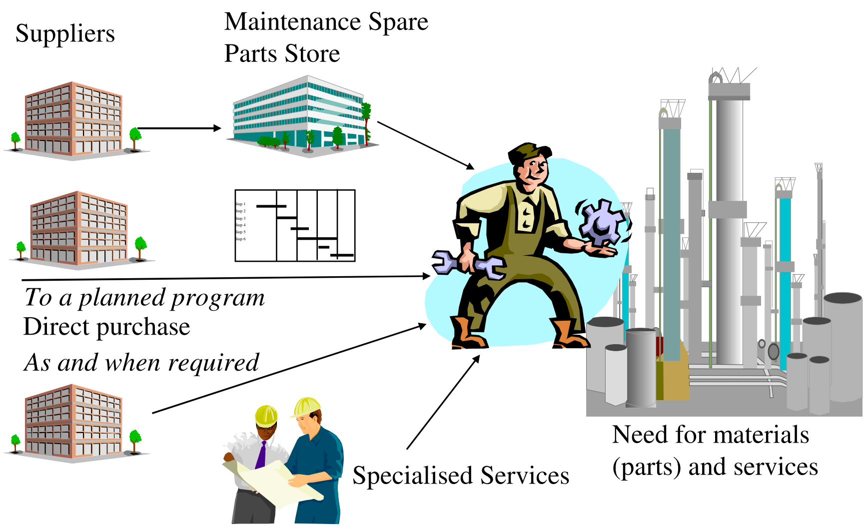
Managing Maintenance Spare Parts

Maintenance Logistics



Inventory

- Inventory is the stock of any item or resource used in an organisation;
- An inventory system is the set of policies and controls that monitors levels of inventories;
- Maintenance inventory is typically in the form of spare parts and rotable units.
- Cost of holding inventory has been found to be 20-25% of the capital value of items held, per annum.

Inventory Management

- An inventory management system tries to answer the following questions:
  - how much to order;
  - when to order;
  - how much to stock.

What are the costs of inventory?

The benefits of maintaining inventory need to be offset against the costs of inventory:

- Holding (or carrying costs) includes:
  - cost of storage facilities
  - handling
  - insurance
  - pilferage
  - breakage and waste
  - obsolescence
  - depreciation
  - taxes
  - opportunity cost of capital
- Setup or changeover costs;
- Ordering costs - managerial and clerical costs to prepare purchase or production orders;
- Shortage cost - stock out cost.

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Independent Demand Inventory

- Demand is independent of time, variable and uncertain;
- Use forecasts, based on historical demand;
- Two major techniques for managing independent demand inventories:
  - Reorder Point (ROP) System - also refered to as fixed-order quantity, economic order quantity (EOQ) or Q model;
  - Periodic Reorder System - also refered to as fixed-time period, periodic review, fixed interval or P model.
- ROP system is event triggered, fixed interval system is time triggered.

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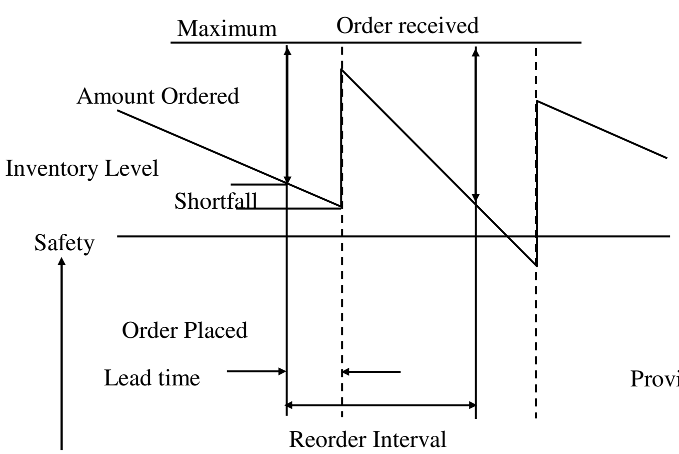
Periodic Reorder System

- Decide on:
  - A maximum stock level
  - A safety of minimum level
  - A reorder interval
  - Order to the maximum level at regularly spaced intervals.

Amount Ordered = Desired Level - actual on hand

Periodic Reorder System

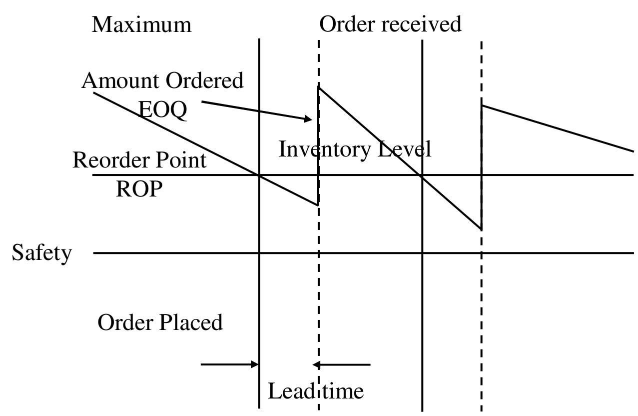


Safety Stocks
Provide a buffer against uncertainty

Reorder Point System (ROP)

- Decide on:
  - A safety or minimum level
  - The reorder point
  - The Reorder Quantity - the Economic Order Quantity
- If there were no uncertainty, ROP would be chosen as 1/2 X Demand + safety level.

Reorder Point System



EOQ Model Assumptions

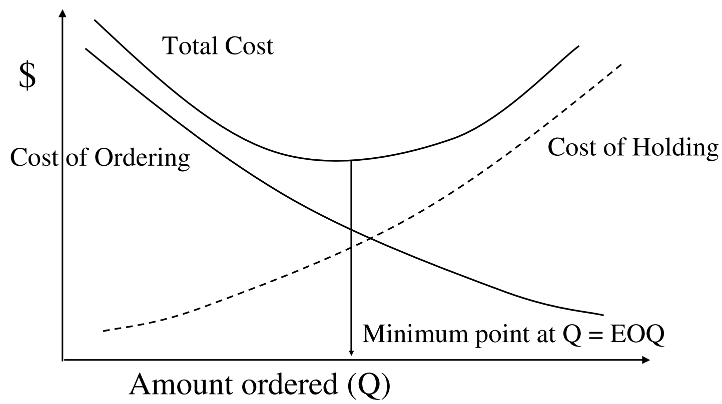
- The usage rate is uniform and known ie. constant demand;
- The item cost does not vary with order size;
- All the order is delivered at the same time;
- Lead time is known well enough that an order can be timed to arrive when inventory is exhausted ie. no stockouts;
- The cost to place and receive an order is the same regardless of the amount;
- the cost of holding inventory is a linear function of the number of items held.

Economic Order Quantity

The Economic Order Quantity (EOQ) is chosen as the order quantity that minimises the total variable costs associated with changing order quantities

Total Variable Costs
= Ordering Costs
+ Carrying Costs

Cost of Ordering vs Cost of Holding



Total Variable Costs

Ordering Costs | Carrying Costs

$$TC = S(D/Q) + iC(Q/2)$$

Cost/order x No. of Orders

Carrying cost % x ave value of inventory

S = Cost per order
D = Demand
Q = Order Quantity
i = period carrying costs
C = Cost per unit of inventory

Economic Order Quantity

Achieved when

Ordering Costs = Carrying Costs

$$S(D/Q) = iC(Q/2)$$

Rearranging

$$EOQ = \sqrt{2SD/iC}$$

Economic Order Quantity Example

Process Plant

- 20 pumps all use the same mechanical seal as the inboard seal;
- Maintenance history and manufacturer's information suggests that the inboard seal will fail once a year on average;
- Cost of the seal is $1,000 per seal;
- The lead time from order to receipt is 4 weeks;
- Cost of ordering = $100 per order;
- Cost of holding stock = 25% of the value of the item.
- Question: How many should be held in stock, what are the key control points?

EOQ Calculations

$$EOQ = \sqrt{\frac{2 \times 100 \times 20}{0.25 \times 1{,}000}}$$

$$EOQ = \sqrt{\frac{4{,}000}{250}} \quad \sqrt{= 16}$$

$$= 4$$

Key Control Parameters

- Set safety stock at say = 1
- During delivery lead time, we are likely to use up to 1 seal;
- Reorder Point needs to be at least 2, make it 3 just to be safe;
- If we receive 4 when stock has run down to 1 we have Maximum stock level of 5, Minimum of 1 and an Average level of 3.

Exercise

- As a result of a recent plant expansion, an additional 5 new pumps are added to the plant;
- Assuming the same failure characteristics for the seal as previously, do we need to revise our stocking levels for this part?

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Safety Stock

- Is intended to provide coverage for demand uncertainty during the lead time period;
- Most organisations settle on an optimal safety stock level for an item, through trial and error;
- Level of safety stock influenced by:
  - How frequently orders are placed;
  - Lead time length (the longer the lead time the more potential for uncertainty);
  - Stability or volatility of demand in general;
  - Relative costs of stockout vs inventory carrying costs.

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Optimising Equipment Maintenance

Statistical Basis for Safety Stock

- Safety Stock can be calculated statistically as:

  safety stock = Z σ

Where:

Z = the Z-value corresponding to the level of service required (based on normal distribution)

  e.g. Service level of 95%, Z = 1.96

σ = the standard deviation of demand during the order lead-time.

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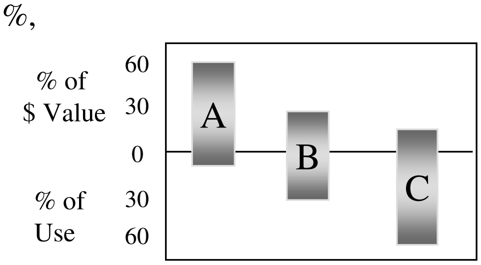
Optimising Equipment Maintenance

ABC Categorisation of Inventory

- Items kept in inventory are not of equal importance in terms of Value, Profit potential, Sales or usage volume, Stock-out penalties etc.
- We identify inventory items based on percentage of total value, where:
  - A : are roughly top 15 %,
  - B : next 35 %,
  - C: the lower 65%



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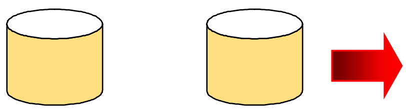
Optimising Equipment Maintenance

Bin Systems

Two-Bin System



Full Empty

Order One Bin of Inventory when one of the Bin's is empty

One-Bin System

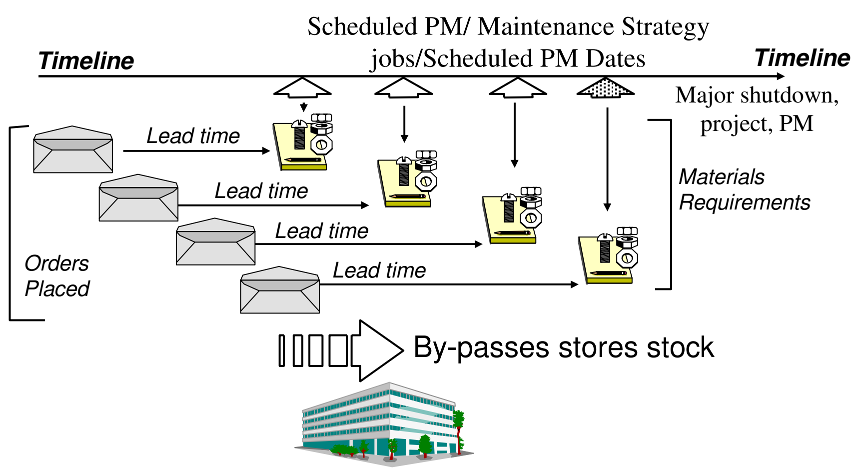
Periodic Check

Order Enough to Refill Bin

Slide 101

Optimising Equipment Maintenance

Dependent Demand Inventories



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Optimising Equipment Maintenance

A Risk Based Approach

Probability of Failure vs Predictability

Is item likely to fail in service?

1. Failures are common with this type of item
2. Item is subject to noticeable wear and tear
3. Item is robust and not subject to undue stress

Is failure predictable?

1. Very difficult or impossible
2. Moderately difficult
3. Relatively easy

Probability			
3	1 X 3	2 X 3	3 X 3
2	1 X 2	2 X 2	3 X 3
1	1 X 1	1 X 2	1 X 3
	1	2	3

Predictability

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Optimising Equipment Maintenance

A Risk Based Approach

Component Inventory Management Strategy

1 X 1	• Item is likely to fail and failure is hard to predict - therefore it is likely to be in the organisation's interest to hold a spare in stock.
1 X 2 1 X 3	• Reduce stock levels if possible
2 X 2 2 X 3	• Question in more detail - do we really need this spare?
3 X 3	• Item is not likely to fail, and if it was, it would be easy to predict. Under these conditions spares availability could be easily coordinated. Therefore it would probably be unnecessary to hold as a spare.

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Optimising Equipment Maintenance

Reliability Based Maintenance Strategy Chart

	Criticality 1				Criticality 2				Criticality 3				Criticality 4			
	Total product lost irretrievably Major Safety/Environmental Impact				Partial Production loss or loss of efficiency. Major Environmental Impact				Increased risk of production or efficiency loss. (Spared equip, by pass control valves etc.)				No Impact on Production			
Differential Maintenance Cost of Failure	High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)		High (>$3,000)		Low (<$3,000)	
Failure Predictable	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Type of Maintenance																
Inspection/Lubrication	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Preventive Maintenance (Task)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	N
Condition Monitoring	Y	N	Y	N	Y	N	Y	N	Y	N	N	N	N	N	N	N
Change Out On Life	N	Y	N	Y	N	Y	N	N	N	Y	N	N	Y	Y	N	N
Run to Failure	N	N	N	N	N	N	N	Y	N	N	Y	Y	N	N	Y	Y
Investigation of Breakdowns	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N
Off-Site Repairs (Assuming can be done on site)					To be decided individually											
Use Rotable																

	Criticality 1			Criticality 2			Criticality 3			Criticality 4		
Value of Rotable Stock	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K	>$100K	$20-100K	<$20K
Repair Time < 1 Day	Y	Y	Y	N	N	N	N	N	N	N	N	N
1-3 Days	Y	Y	Y	N	N	Y	N	N	N	N	N	N
3-15 Days	Y	Y	Y	Y	Y	Y	N	N	Y	N	N	N
>15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N

	Criticality 1						Criticality 2						Criticality 3						Criticality 4					
Stock Holdings (Items< $20,000) (Whether to Hold Stock or Not)	Assumes no Rotable Stock held for the part																							
Value of Total Stock Holding	$2,000 - -$20,000		$500- -$2,000		<$500		$2,000 - -$20,000		$500- -$2,000		<$500		$2,000 - -$20,000		$500- -$2,000		<$500		$2,000 - -$20,000		$500- -$2,000		<$500	
Failure Predictable?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Lead Time																								
< 1 Day (Avail Ex. Stock-Local)	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
1-5 Days (Avail Ex. Stock-Country)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N
5-15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N	N	N	N
>15 Days	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N

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Optimising Equipment Maintenance

Slide 106

RCM Analysis - Function and Functional Failure

Unit :

System :

System Function	Functional Failure

RCM Analysis - Maintainable Item and Functional Failure Table

Unit : *Crude Stabilisation Plant*

System : *Reboiler System*

Functional Failure Maintainable Item																				

RCM Analysis - Failure Modes and Effects Analysis

Unit**:**

System:

Function	**Functional Failure**	**Failure Mode**	**Failure Effect**	**Criticality**	**Response**

RCM Analysis - Failure Modes and Effects Analysis

Unit**:**

System:

Function	**Functional Failure**	**Failure Mode**	**Failure Effect**	**Criticality**	**Response**

RCM Analysis - Failure Modes and Effects Analysis

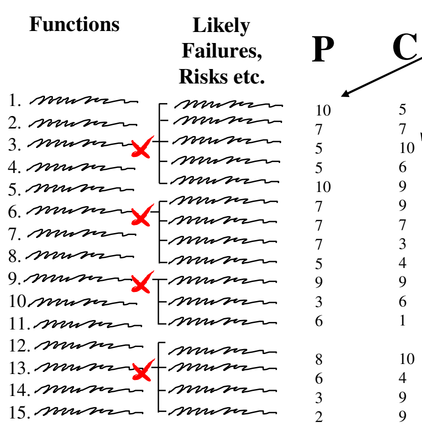
Unit**:**

System:

Function	**Functional Failure**	**Failure Mode**	**Failure Effect**	**Criticality**	**Response**

Risk Based Inspection Strategies

An Approach to Quantitative Risk Analysis



<u>Probability</u>

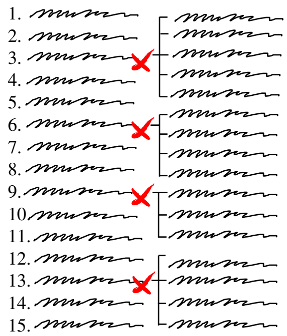
Use a numerical scoring approach instead of H, M, L for probability.

<u>Consequences</u>

Use a numerical scoring approach instead of H, M, L for consequences.

Risk = Probability X Consequences

Functions **Likely Failures, Risks etc.**



P	X	C	= Risk
10		5	50
7		7	49
5		10	50
5		6	30
10		9	90
7		9	63
7		7	49
7		3	21
5		4	20
9		9	81
3		6	18
6		1	6
8		10	80
6		4	24
3		9	27
2		9	18

Quantified value for risk calculated as:

Risk = Probability X Consequences

Calculated value is used to determine <u>Criticality</u> and to <u>Rank</u> the Risks

Determining Probabilities

- Analysis of History
  - Pareto Analysis
- Monte Carlo Simulation
- Fault Tree Analysis
- HAZOP Analysis
- Industry and 3rd Party Statistics
  - Tables and graphs
  - Manufacturer’s data

Optimising Equipment Maintenance

Calculation of Probability of Failure

E.g. Pipes and Vessels

Degradation Mechanism → Damage → Load vs Strength → Failure Mode

Degradation Mechanism
- Corrosion
- Fatigue
- Erosion

Damage
- Pitting
- Cracks
- Wall loss

→ Inspection

Load vs Strength
- Geometry
- Material Type
- Stress Intensity
- Remaining Wall

→ Probability of Failure

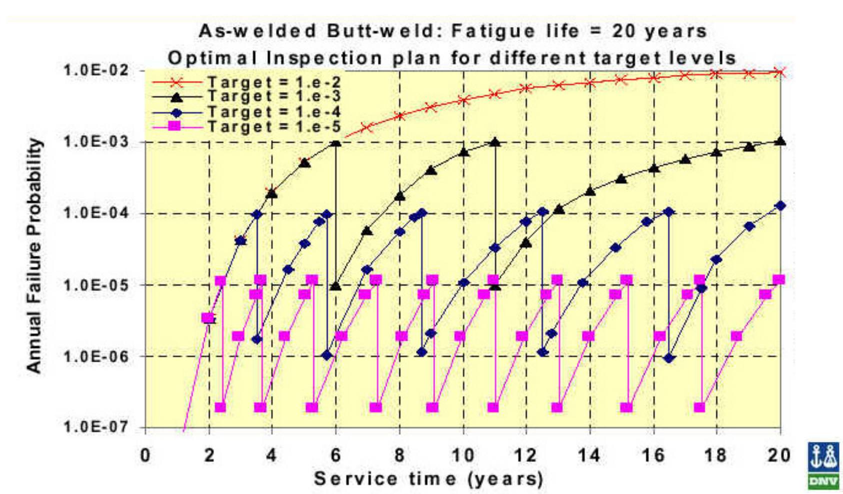
Failure Mode
- Pinhole leak
- Brittle fracture
- Burst
- ….

→ Consequences

 Slide 5

Optimising Equipment Maintenance

Selection of Inspection Scheduling Program - Example



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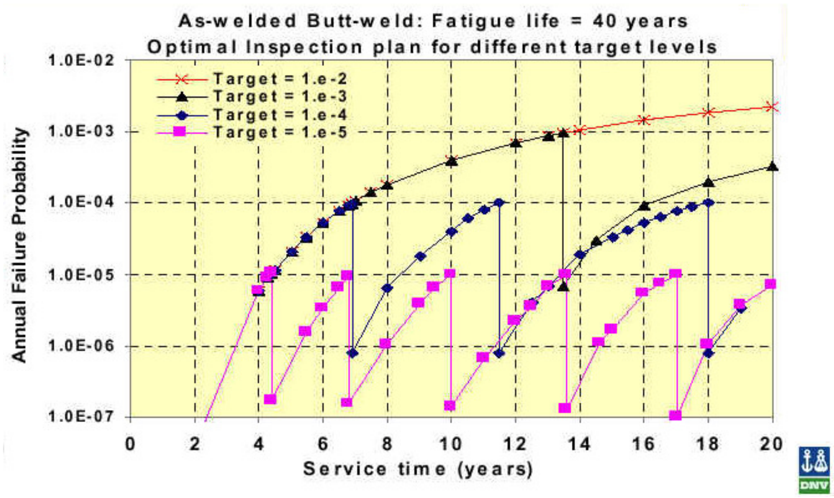
Selection of Inspection Scheduling Program - Example



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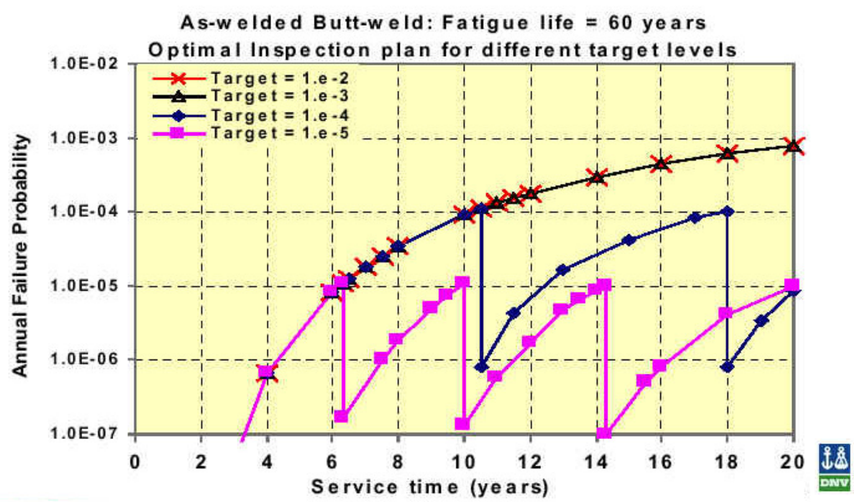
Optimising Equipment Maintenance

Selection of Inspection Scheduling Program - Example



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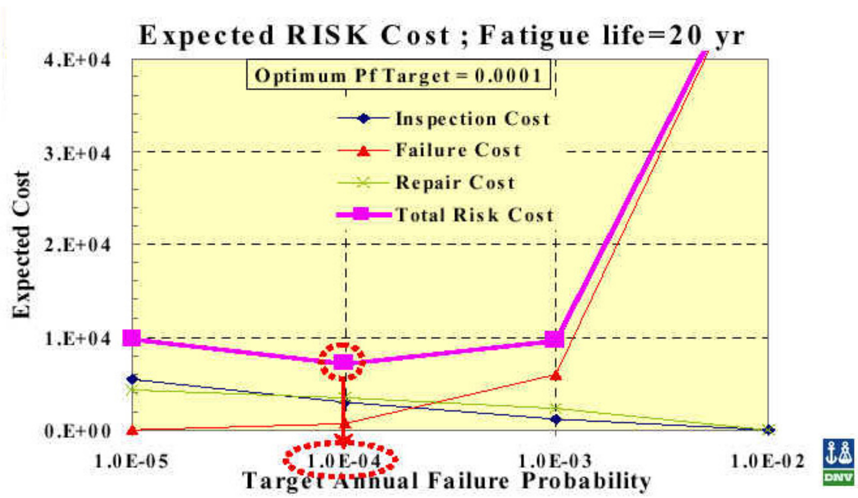
Optimising Equipment Maintenance

Cost Terms

- Expected Failure Cost : US $ 1.4 Million
- Expected Inspection Cost: US $1,000
- Expected Repair Cost: US $10,000
- Discount Rate: 6%

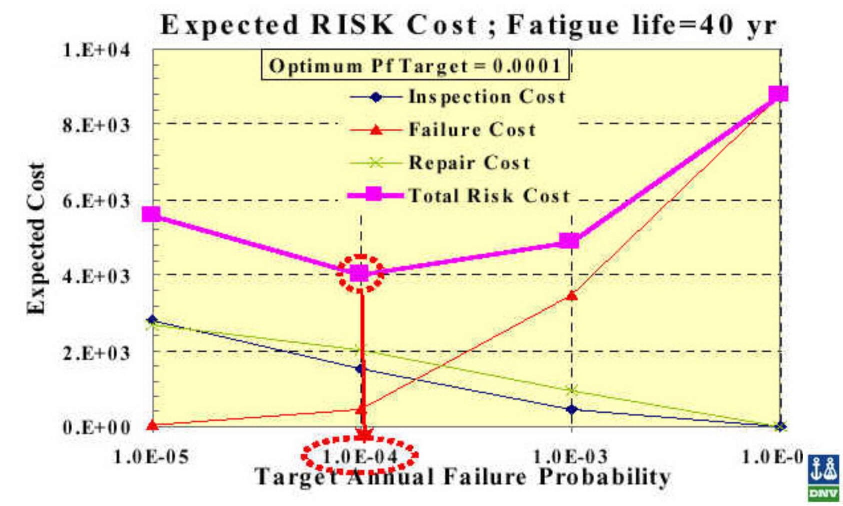
Optimising Equipment Maintenance

Selection of Inspection Scheduling Program - Example



Optimising Equipment Maintenance

Selection of Inspection Scheduling Program - Example



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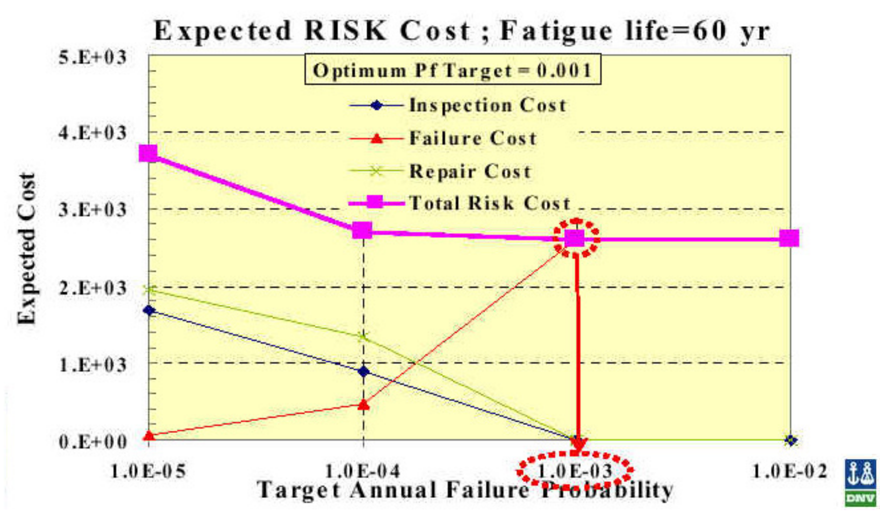
Selection of Inspection Scheduling Program - Example



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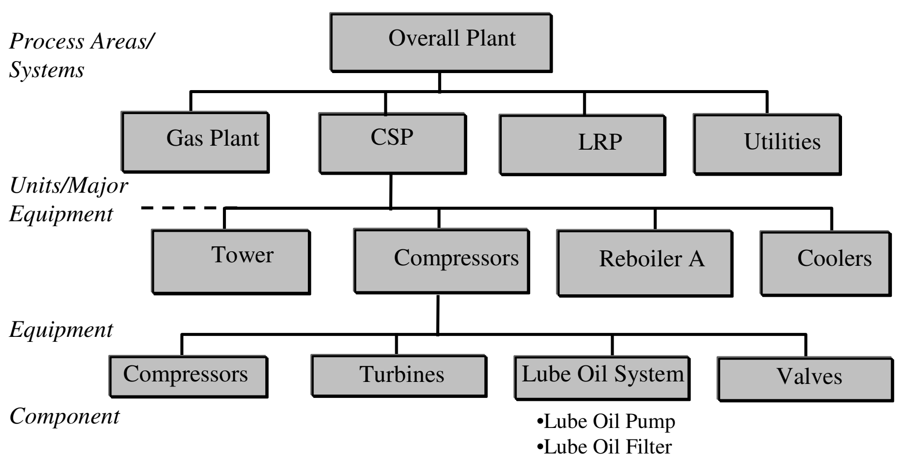
Applying RBM at Different Levels

 Slide 13

Plant Hierarchy

Petrochemical Plant



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Optimising Equipment Maintenance

Applying RBM at the Plant Level

- Generally identifies equipment items that are parts of the system.

Systems: 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15.

Likely Failures, Risks etc.	P	X C	= Risk
	10	5	50
	7	7	49
	5	10	50
	5	6	30
	10	9	90
	7	9	63
	7	7	49
	7	3	21
	5	4	20
	9	9	81
	3	6	18
	6	1	6
	8	10	80
	6	4	24
	3	9	27
	2	9	18

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Optimising Equipment Maintenance

Applying RBM at the Plant Level

Systems: 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15.

Units/ Equipment.	P	X C	= Risk	Risk Rating/ Criticality
	10	5	50	2
	7	7	49	2
	5	10	50	2
	5	6	30	3
	10	9	90	1
	7	9	63	1
	7	7	49	2
	7	3	21	3
	5	4	20	3
	9	9	81	1
	3	6	18	3
	6	1	6	4
	8	10	80	1
	6	4	24	3
	3	9	27	3
	2	9	18	3

- Used to prioritise assets for further analysis

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Optimising Equipment Maintenance

Plant Area/System Level QRA Summary

Table 1. Top Ten High Risk Items

Equipment Type	Description	Risk Value	Primary Damage Mechanism	Likelihood Factor	Consequence Factor	Likelihood Category	Consequence Category
EXCHANGER	Reformer Gas Boiler-Shell	3330	HTHA	1800	11860	5	E
HEATER	Primary Reformer Tubes	1104	Creep	5000	33457	5	E
VESSEL	Ammonia Converter	950	HTHA	800	7610	4	E
VESSEL	Purge Gas Ammonia Stripper	204	Internal Thinning	265	4933	4	E
2" PIPE	NH3 Stripper	4	Internal Localized Thinning and CUI	485	2381	4	E
4" PIPE	Syn Gas Chiller	4	Internal Thinning and CUI	96	26097	3	E

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Optimising Equipment Maintenance

Risk Ranking Matrix with Equipment Distribution for Plant

Likelihood Category	A	B	C	D	E	
5			1			1
4	29	11	25	41	22	128
3	2			4	7	13
2	1		1	6	3	11
1	14	5	14	40	27	100
	46	16	41	91	59	

(Columns A–E: Consequence Category)

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Optimising Equipment Maintenance

Select Critical Assets for further analysis

Identifies Critical Equipment

Table 1. Top Ten High Risk Items

Equipment Type	Description	Risk Value	Primary Damage Mechanism	Likelihood Factor	Consequence Factor	Likelihood Category	Consequence Category
EXCHANGER	Reformer Gas Boiler-Shell	3330	HTHA	1800	11860	5	E
HEATER	Primary Reformer Tubes	1104	Creep	5000	33457	5	E
VESSEL	Ammonia Converter	950	HTHA	800	7610	4	E
VESSEL	Purge Gas Ammonia Stripper	204	Internal Thinning	265	4933	4	E
2" PIPE	NH3 Stripper	4	Internal Localized Thinning and CUI	485	2381	4	E
4" PIPE	Syn Gas Chiller	4	Internal Thinning and CUI	96	26097	3	E

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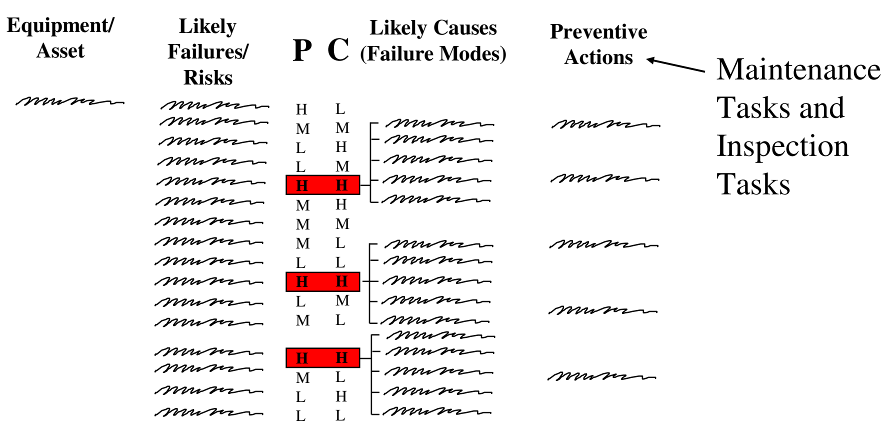
Optimising Equipment Maintenance

Applying QRA at the Asset/Equipment Level



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Risk Ranking Matrix

Probability (HIGH at A, LOW at E); Consequences (LOW at 1, HIGH at 5)

Probability	1	2	3	4	5
A	H	H	E	E	E
B	M	H	H	E	E
C	L	M	H	E	E
D	L	L	M	H	E
E	L	L	M	H	H

E EXTREME RISK
H HIGH RISK
M MODERATE RISK
L LOW RISK

Inspection Planning Recommendations

Table 2. Inspection Planning Recommendations.

Equipment ID	Description	Risk Rank	Likelihood Driver	Damage Factor without Inspection by 2005	Damage Factor with Inspection by 2005	Recommended Internal Thinning Inspection Level	Comments
Exchanger	Reformer Gas	High	HTHA, Highly suscep-tible	2000	800	2B	Maximum interval of 2.5 years to maintain factor of 400 minimum value only (for CS only). The recommended inspection technique involves a combination of Backscatter, Velocity Ratio, and Spectrum Analysis followed up with field metallography. See Inspection Effectiveness Tables for HTHA.

Module 3:

Condition Monitoring and Statistical Methods in Maintenance

Module 4:

Economics of Reliability

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Economics of Reliability

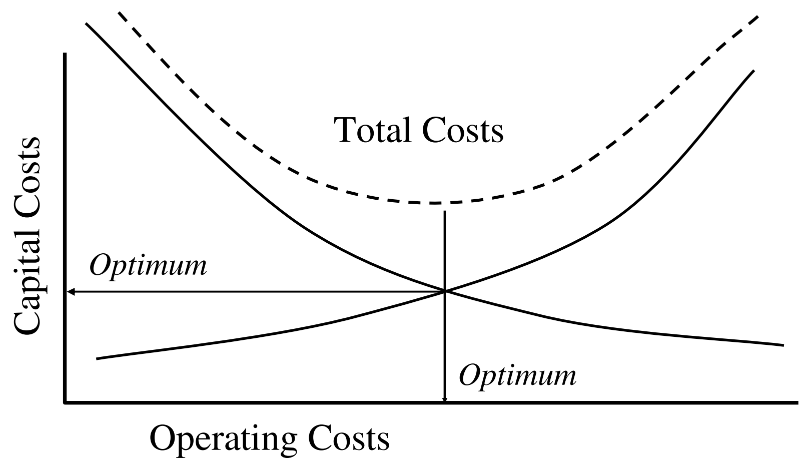
 Slide 1

Introduction to Discounted Cashflow Analysis and Capital Decision Making

 Slide 2

Optimising Equipment Maintenance

Capex vs Opex



 Slide 3

Optimising Equipment Maintenance

Financial Assessment Techniques

- Payback
- Discounted Cashflow Techniques
  - Net Present Value (NPV)
  - Internal Rate of Return (IRR)

 Slide 4

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Project Cash Flows

- We apply our financial analysis techniques to the net cash inflow generated by a project;
- Net Cash Inflow

  = Incoming cash flow - Outgoing cash flow

  Due to the project

Typical Project Cash Flows

- Incoming Cash Flows:
  – Additional sales revenue, cost reductions, revenue from asset sales (eg. salvage);
- Outgoing Cash Flows:
  – Operating costs during project life, taxes, increases in working capital, interest on loans (except where NPV and IRR methods used).

Optimising Equipment Maintenance

The Payback Method

Years	0	1	2	3	4	5
Project A						
Initial investment	$1,000			*Initial $1,000 Paid Back*		
Net cash inflow		$400	$400	$200	$100	
Project B					*Initial $1,000 Paid Back*	
Initial Investment	$1,000					
Net cash inflow		$100	$200	$300	$400	$600

Project A above has a payback of 3 years . ie. the initial investment of $1,000 is recovered after 3 years.

Project B has a payback of 4 years

Slide 7

Optimising Equipment Maintenance

The $1,000 Investment

- You have $1,000 to invest;
- You are able to find a Bank that will give you 10% interest (with no fees) if you leave it in your account for 1 year;
- How much will you have at the end of 1 year?
- Assuming no withdrawals, how much will you have at the end of 2 years?
- At the end of 3 years?

Slide 8

The $1,000 Project

- A friend has asked you to invest in a project;
- The investment they require is $1,000;
- You will get you initial money back plus your share of the profit, in three years time;
- How much would you expect to get back for you to be interested?

 Slide 9

The $1,000 Investment Calculations

$1,000 x (1.1) = $1,100 at the end of 1 year

$1,100 x (1.1) = $1,210 at the end of 2 years

$1,210 x (1.1) = $1,331 at the end of 3 years

= $1,000 x (1.1) x (1.1) x (1.1)

Multiply by 1 + the interest rate for each year

 Slide 10

The Time Value of Money

- The fact that our $1,000 is worth $1,331 in years time if we just leave it in the bank is referred to the *Time Value of Money*;
- The "do nothing" option has real value because of the time value of money;
- Any proposed investment, must outperform the do nothing option.

In general ….

The future value (FV) of any sum of money we have today (PV or Present Value) can be found using the formula …….

$$FV = PV(1 + r)^n$$

Where n = number of years
and r = interest rate

Projects and the Time Value of Money

- Projects produce benefits which are realised in the future - in the form of net cash flows. These are future values (FV's);
- Our investment is usually required now. This is a PV;
- To compare the future benefits to today's investment, we need to work out what the future benefits are worth in today's money (PV's).

Calculating Project Benefit PV's

$$PV = \frac{FV}{(1 + r)^{n}}$$

Consider Project A and Project B

Years	0	1	2	3	4	5
Project A						
Initial investment	$1,000					
Net cash inflow		$400	$400	$200	$100	
Project B						
Initial Investment	$1,000					
Net cash inflow		$100	$200	$300	$400	$600

Present Value of Net Future Cash Flows: Project A

$$= \frac{\$400}{(1.1)} + \frac{\$400}{(1.1)^2} + \frac{\$200}{(1.1)^3} + \frac{\$100}{(1.1)^4}$$

$$= \frac{\$400}{1.1} + \frac{\$400}{1.21} + \frac{\$200}{1.331} + \frac{\$100}{1.464}$$

$$= \$363.64 + \$330.58 + \$150.3 + \$68.3$$

$$= \$912.78$$

$$= \$\,913$$

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Net Present Value: Project A

Present Value of Future Cash Flows — Present Value of Investment

$ 913 — $ 1,000

= - $ 87 Net Present Value (NPV)

 Slide 17

Present Value of Net Future Cash Flows: Project B

$$= \frac{\$100}{(1.1)} + \frac{\$200}{(1.1)^2} + \frac{\$300}{(1.1)^3} + \frac{\$400}{(1.1)^4} + \frac{\$600}{(1.1)^5}$$

$$= \frac{\$100}{1.1} + \frac{\$200}{1.21} + \frac{\$300}{1.331} + \frac{\$400}{1.464} + \frac{\$600}{1.61}$$

$$= 90.9 + 165.3 + 225.39 + 273.21 + 372.67$$

$$= \$1,127.47$$

$$= \$1,127$$

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Net Present Value: Project B

Present Value of Future Cash Flows	−	Present Value of Investment
$ 1,127	−	$ 1,000

= $ 127 Net Present Value (NPV)

What does NPV mean ?

- NPV is a direct measure of the amount of value a project creates in financial terms;
- A Positive NPV project creates value;
- A Zero NPV project neither creates nor dissipates value;
- A Negative NPV project dissipates or destroys existing value.

Some key terms

- Risk Free Rate
- Risk Premium
- Cost of Capital
- Weighted Average Cost of Capital (WACC)
- Discount Rate

Internal Rate of Return (IRR)

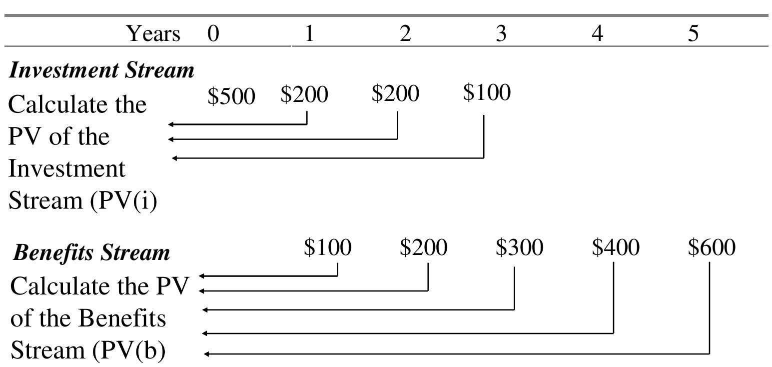
- Internal rate of return is the rate of return which results in an NPV of zero;
- Is a measure of the rate at which a project generates NPV;
- Can be effectively used to prioritise projects and other activities requiring the investment of funds.

Prioritisation Techniques

- Once NPV has been used to filter out undesirable projects and investment opportunities, the remaining may be prioritised by a number of techniques:
  - IRR;
  - Payback
  - Various NPV ratios – NPV/Years, NPV/Investment, NPV p.a./Investment p.a.

 Slide 23

Dealing with time phased investment



NPV = PV(b) – PV(i)

 Slide 24

Life Cycle Cost Concepts

 Slide 25

Life Cycle Costing

- The basic concept of Life Cycle Costs is that equipment acquisition and maintenance decision should be made on the basis of the "total cost of ownership" for that equipment, not just the lowest purchase cost (Capex) or lowest operating costs (Opex).

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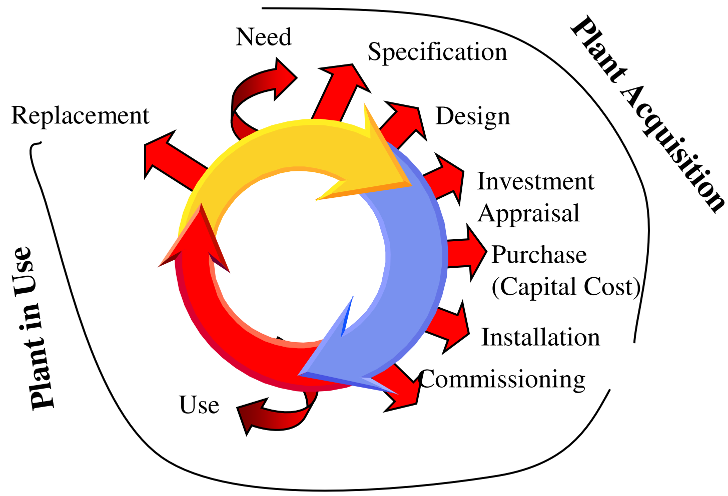
Optimising Equipment Maintenance

The Plant Life Cycle



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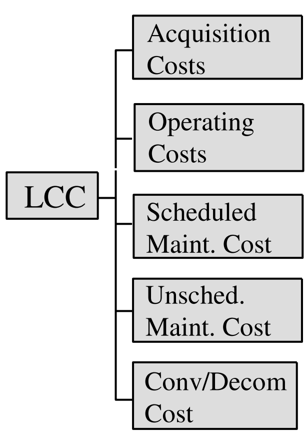
Optimising Equipment Maintenance

LCC Cost Elements



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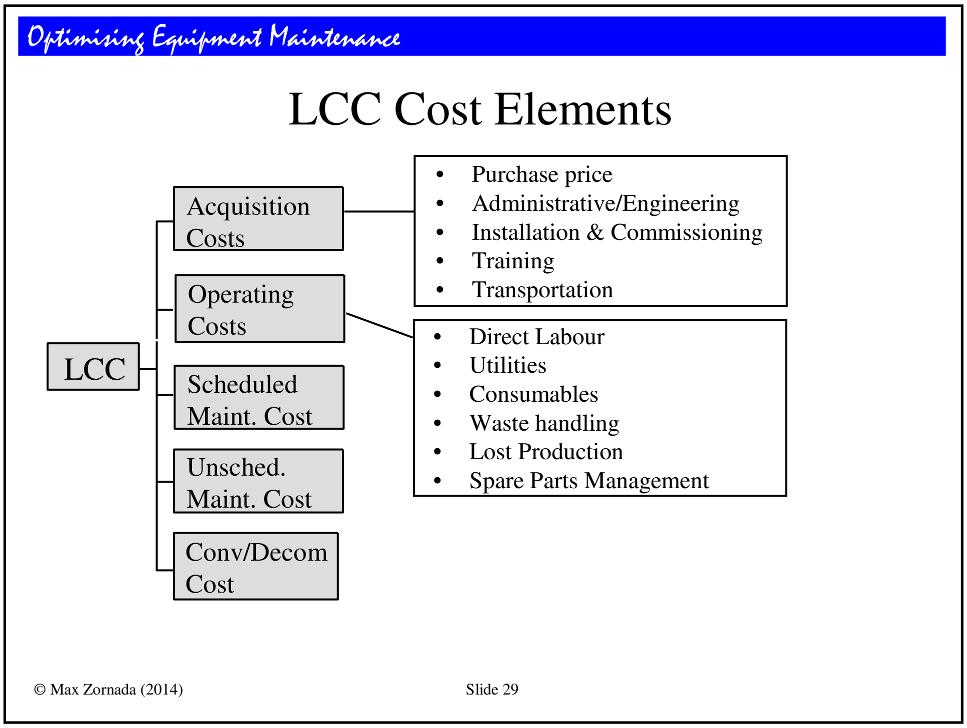
Optimising Equipment Maintenance
LCC Cost Elements
LCC
Acquisition Costs
Operating Costs
Scheduled Maint. Cost
Unsched. Maint. Cost
Conv/Decom Cost
• Purchase price
• Administrative/Engineering
• Installation & Commissioning
• Training
• Transportation
• Direct Labour
• Utilities
• Consumables
• Waste handling
• Lost Production
• Spare Parts Management
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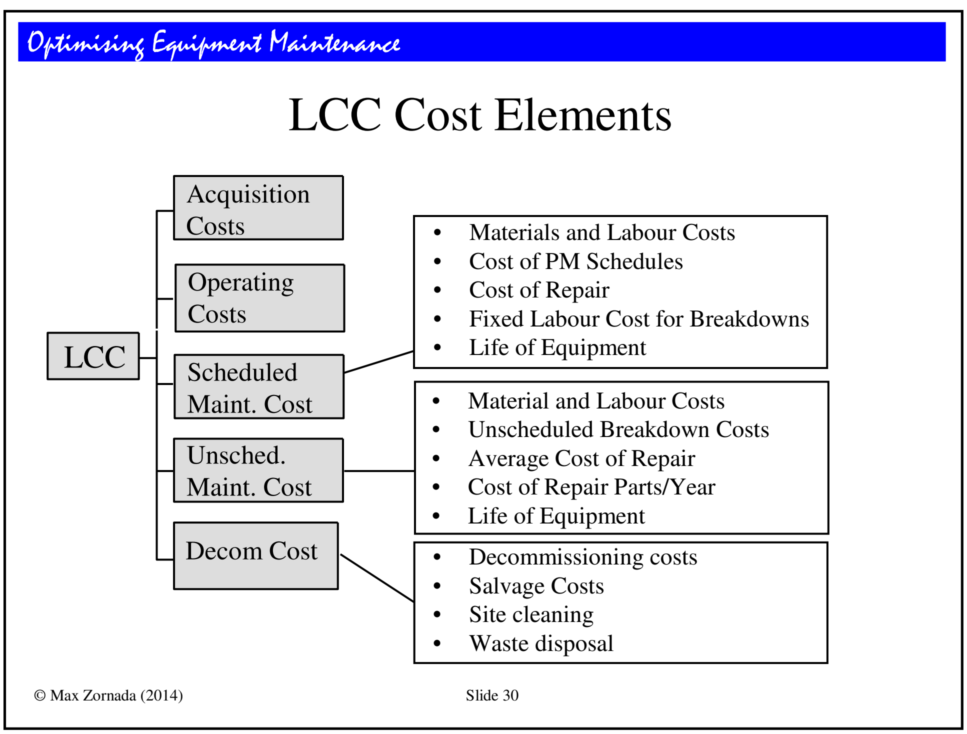
Optimising Equipment Maintenance
LCC Cost Elements
LCC
Acquisition Costs
Operating Costs
Scheduled Maint. Cost
Unsched. Maint. Cost
Decom Cost
• Materials and Labour Costs
• Cost of PM Schedules
• Cost of Repair
• Fixed Labour Cost for Breakdowns
• Life of Equipment
• Material and Labour Costs
• Unscheduled Breakdown Costs
• Average Cost of Repair
• Cost of Repair Parts/Year
• Life of Equipment
• Decommissioning costs
• Salvage Costs
• Site cleaning
• Waste disposal
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Simplified LCC Case Study

	Pump 1	Pump 2
Purchase price	$10,000	$15,000
Annual cost of breakdowns	$150	$60
Operating Costs	$1,000	$850
Consumable costs	$150	$100
Cost of Preventive Maint.	$250	$300
Salvage Value	$2,000	$10,000

- Pump is intended to be operated for 5 years before disposal.

Pump 1 LCC

Year	0	1	2	3	4	5
Purchase Price						
Annual cost of breakdowns						
Operating Costs						
Consumables costs						
Cost of Preventive Maint.						
Total Cost						
PV of Costs						
Salvage Value						
PV of Salvage Value						
Net PV Cost						

Pump 2 LCC

Year	0	1	2	3	4	5
Purchase Price						
Annual cost of breakdowns						
Operating Costs						
Consumables costs						
Cost of Preventive Maint.						
Total Cost						
PV of Costs						
Salvage Value						
PV of Salvage Value						
Net PV Cost						

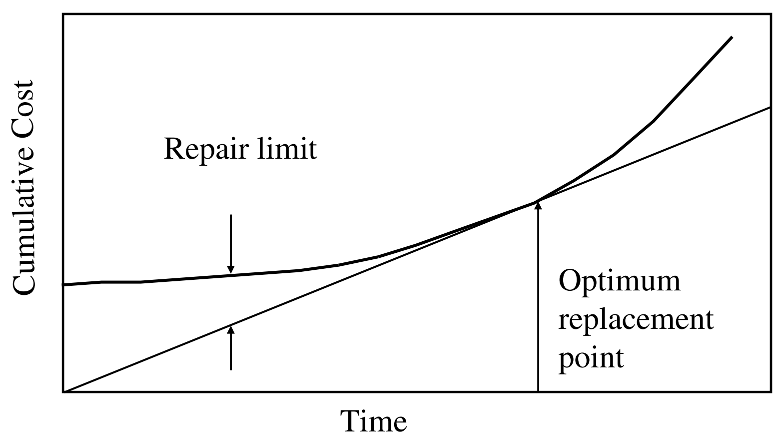
Key Uncertainties in LCC

- Equipment life;
- Cost of Breakdowns;
- Cost of Preventive and Proactive Maintenance
  - Impact of these on Breakdown and Operating Costs.
- Cost and impact of various maintenance strategies;
- Salvage value at the end;

Overcoming the Uncertainties in LCC

- Accurate equipment history and cost record keeping;
- Modelling various scenarios:
  - Best Case
  - Worst Case
  - Most likely Case
- Statistical and Probabilistic modelling e.g. Monte Carlo Analysis

Repair/Replace Decisions



Optimising Equipment Maintenance

Case Study: Repair/ Replace

		Cost	Cummulative
Purchase Price: Year 0		$20,000	
Operating and Maintenance Cost	Year 1	$ 200	
	Year 2	$ 200	
	Year 3	$ 400	
	Year 4	$ 400	
	Year 5	$ 600	
	Year 6	$ 600	
	Year 7	$ 1200	
	Year 8	$ 1600	
	Year 9	$ 2000	
	Year 10	$ 2400	
	Year 11	$ 2600	
	Year 12	$ 2800	
	Year 13	$ 4000	
	Year 14	$ 5000	
	Year 15	$ 6000	

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Optimising Equipment Maintenance

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Optimising Equipment Maintenance

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Module 4:

Economics of Reliability

Templates

Pump 1 LCC

Year	0	1	2	3	4	5
Purchase Price						
Annual cost of breakdowns						
Operating Costs						
Consumables costs						
Cost of Preventive Maint.						
Total Cost						
PV of Costs						
Salvage Value						
PV of Salvage Value						
Net PV Cost						

Pump 2 LCC

Year	0	1	2	3	4	5
Purchase Price						
Annual cost of breakdowns						
Operating Costs						
Consumables costs						
Cost of Preventive Maint.						
Total Cost						
PV of Costs						
Salvage Value						
PV of Salvage Value						
Net PV Cost						

Optimising Equipment Maintenance

Module 5:

Effective Management of Maintenance Resources and Information

The Maintenance Strategy Process

Business Level Strategies for Maintenance

↓

Organisational Level Maintenance Strategies & Policies

↓

Asset Specific Maintenance Strategies

↓

Implement and Monitor

The Maintenance Strategy Process

Business Level Strategies for Maintenance

↓

Organisational Level Maintenance Strategies & Policies

↓

Asset Specific Maintenance Strategies

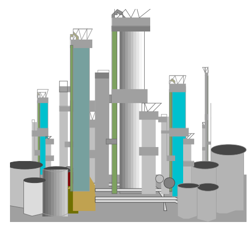
↓

Implement and Monitor

→ Reliability Based Maintenance and Reliability Based Thinking, impacts decisions at this level.

Organisational Level Maintenance Strategies and Policies

- Is about making appropriate choices about all the strategic factors for specific groups or assets or processes within the framework of the managerial level strategies and policies for maintenance.



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Organisational Level Maintenance Strategies and Policies

Decision Areas

- Maintenance Philosophy
- Maintenance objectives
- Maintenance budgeting and cost management
- Resource Structure (Electricians, Fitters etc.)
- Resource Levels
- Management Structure
- Preventive Maintenance Levels
- Preventive Maintenance Types
- Backlog Levels
- Work Location (in-situ, in-house, external)
- Use of contractors
- Workshop facilities
- Purchasing and Stores Policies
- Inventory Levels
- Use of Rotable Spares
- Planning and Scheduling Approach
- Coordination with production

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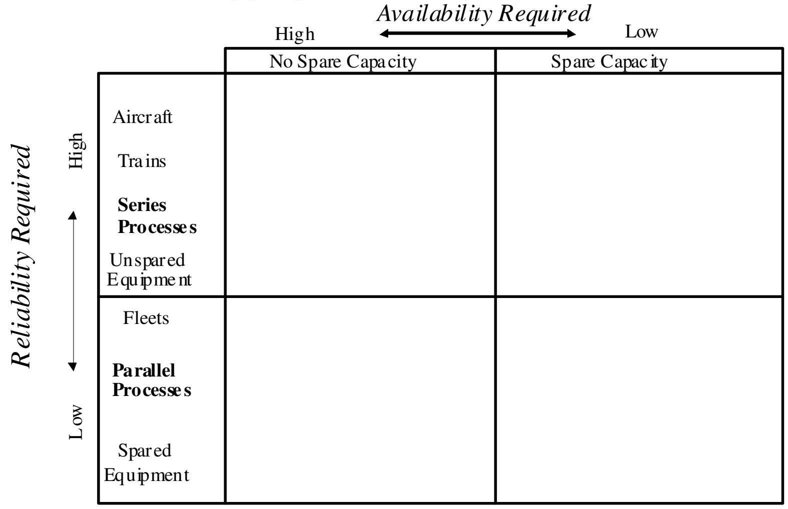
Optimising Equipment Maintenance

The Maintenance Management Strategy Matrix

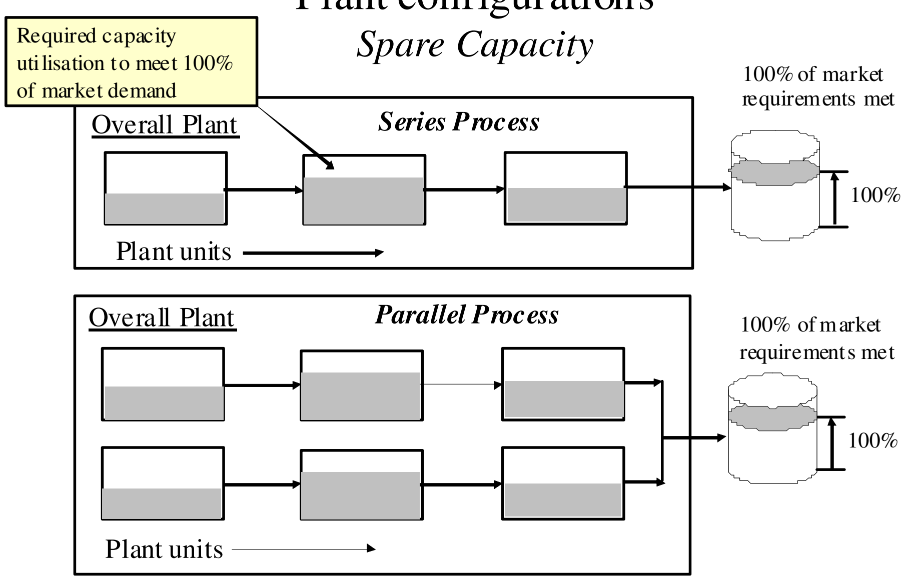
Plant Structure and Market Dynamics determine the most appropriate strategy



Optimising Equipment Maintenance

Plant configurations

Spare Capacity



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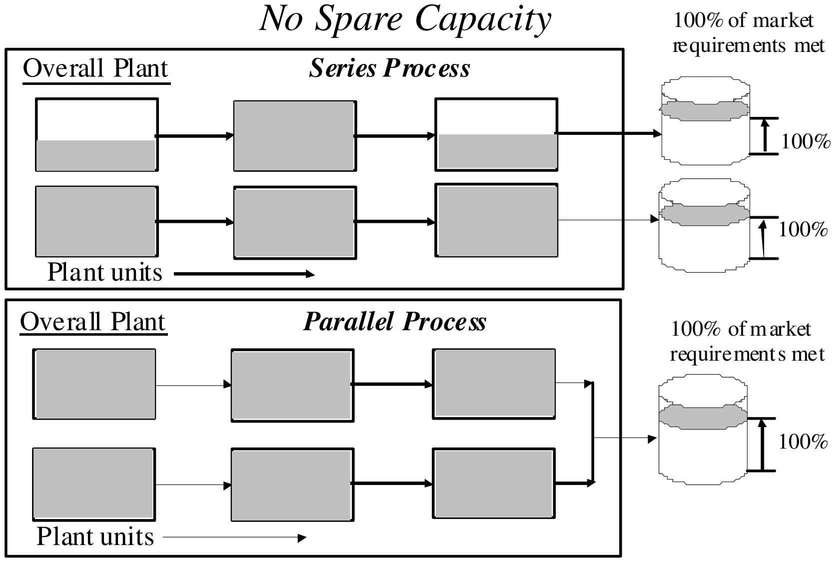
Optimising Equipment Maintenance

Plant configurations

No Spare Capacity



Optimising Equipment Maintenance

The Maintenance Management Strategy Matrix

Plant Structure and Market Dynamics determine the most appropriate strategy

Availability Required: High ↔ Low

Reliability Required: High ↕ Low

Reliability Required	Plant	No Spare Capacity (High availability)	Spare Capacity (Low availability)
High	Aircraft Trains **Series Processes** Unspared Equipment	Use Rotables High Inventory Spares 24 Hour maintenance High Level of PM Maintain Low Backlog Resource Levels to handle peaks On-site workshops	No Rotables Low Inventory Spares Day Shift maintenance High Level of PM Maintain Low Backlog Resource Levels for Hollows, use Contractors/Overtime Off-site Repairs
Low	Fleets **Parallel Processes** Spared Equipment	Use Rotables High Inventory Spares 24 Hour maintenance Medium Level of PM Schedule Job Packets Resource for average plus overtime On-site Workshop	No Rotables Low Inventory Spares Day Shift maintenance Breakdown Maintenance Let Backlog Drift Minimum Resources Minimum Overtime Off-site Repairs

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Maintenance Strategy Development

Organisational Level Maintenance Strategies and Policies

Case Study

Southern Petrochemical Company

Gas Processing Operations

Gas Processing Operations

Case Notes

- SPC's Gas Processing Plant is shown in the schematic in Figure 1.
- Gas and Crude Oil are received at the plant inlet area - the gas goes to the Gas Separation unit the oil to the Crude Stabilisation Plant (CSP). Hydrocarbon condensate which is recovered in the gas separation unit is also fed to the CSP. Gas Separation area must be operating at 100% capacity for normal operations.
- Flash Gas from the CSP is fed to the Gas Sweetening Plant which has 3 trains. Two are required to be operating at full capacity for normal operations.
- Stabilised crude is pumped to the Tank Farm where it is stored awaiting shipment. The Gas Plant can operate independently of the CSP. However, a failure of the CSP will shut down the oil side of the operation.
- Sweetened gas goes to the Liquids Recovery Plant where it is cooled and further Hydrocarbon Liquids are recovered. These are routed back to the CSP. The LRP was designed such that it can meet normal operating requirements at 80% capacity.
- Cold, dry gas goes to the De-methaniser unit, where two towers operate. De-methaniser bottoms progress to the De-ethaniser unit, the methane progresses to the methane compressors, where it is compressed to full pipeline pressure for sales.
- The ethane from the De-ethaniser Unit goes to the Ethane Compressors where it is compressed for storage in bullets, awaiting further distribution.
- The De-ethaniser bottoms (NGL's) are routed to storage bullets awaiting further sales.
- The Methane and Ethane compressors units are made up of 3 compressors, only 2 of which need to be operating for normal operations.
- The De-methaniser and De-ethaniser units need to be operating at 80% capacity for normal operations.
- Stabilised Crude sales generates the most revenue for the company and there is always pressure to maximise the output of stabilised crude. However, the company is tied in to gas supply contracts to several major cities and their electricity utility companies. Operational problems or unanticipated reductions in production in the gas plant have the potential to cause severe disruption to their customers which would result in legal action and claims for compensation.

Figure 1. Gas Processing Plant Schematic

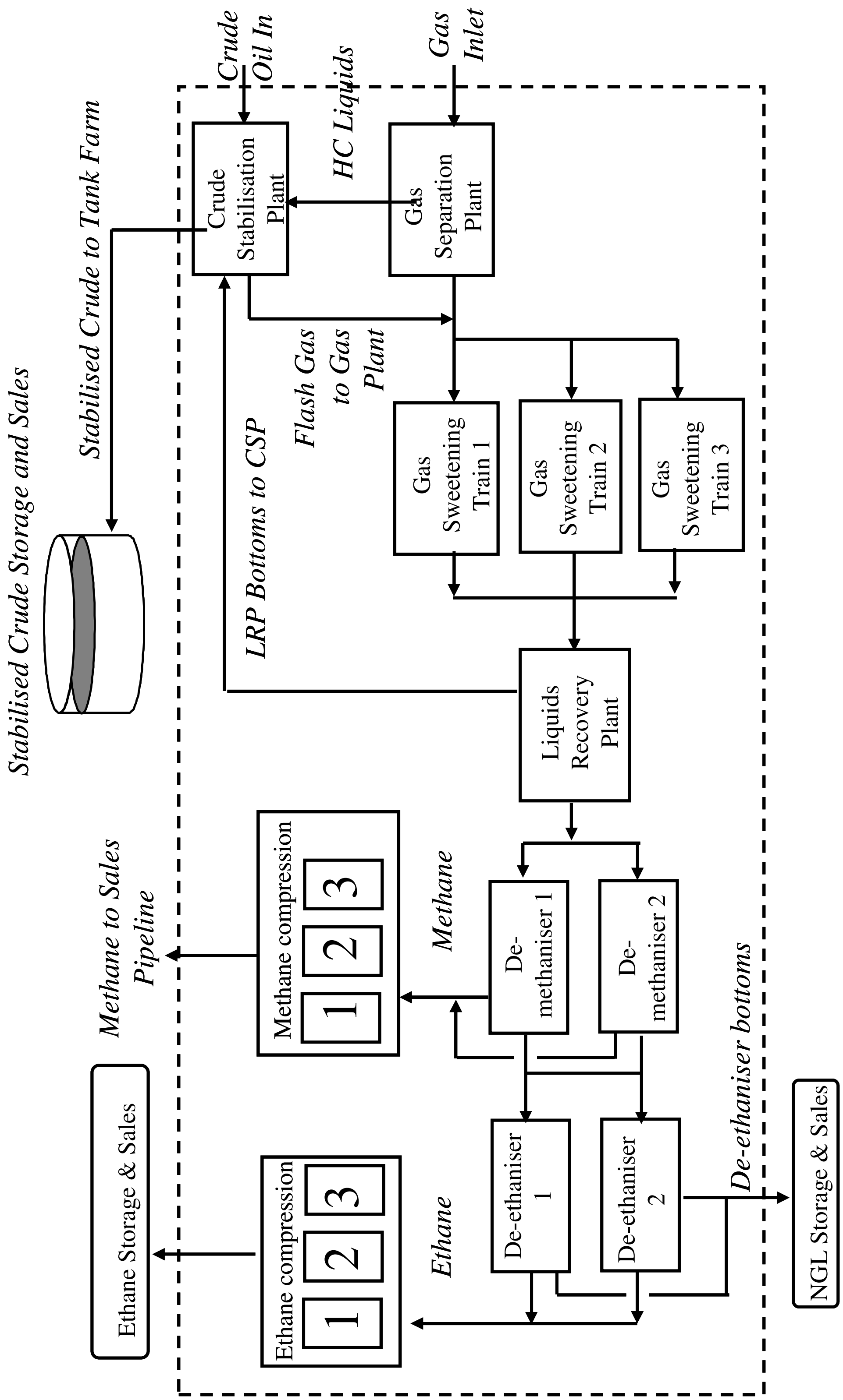
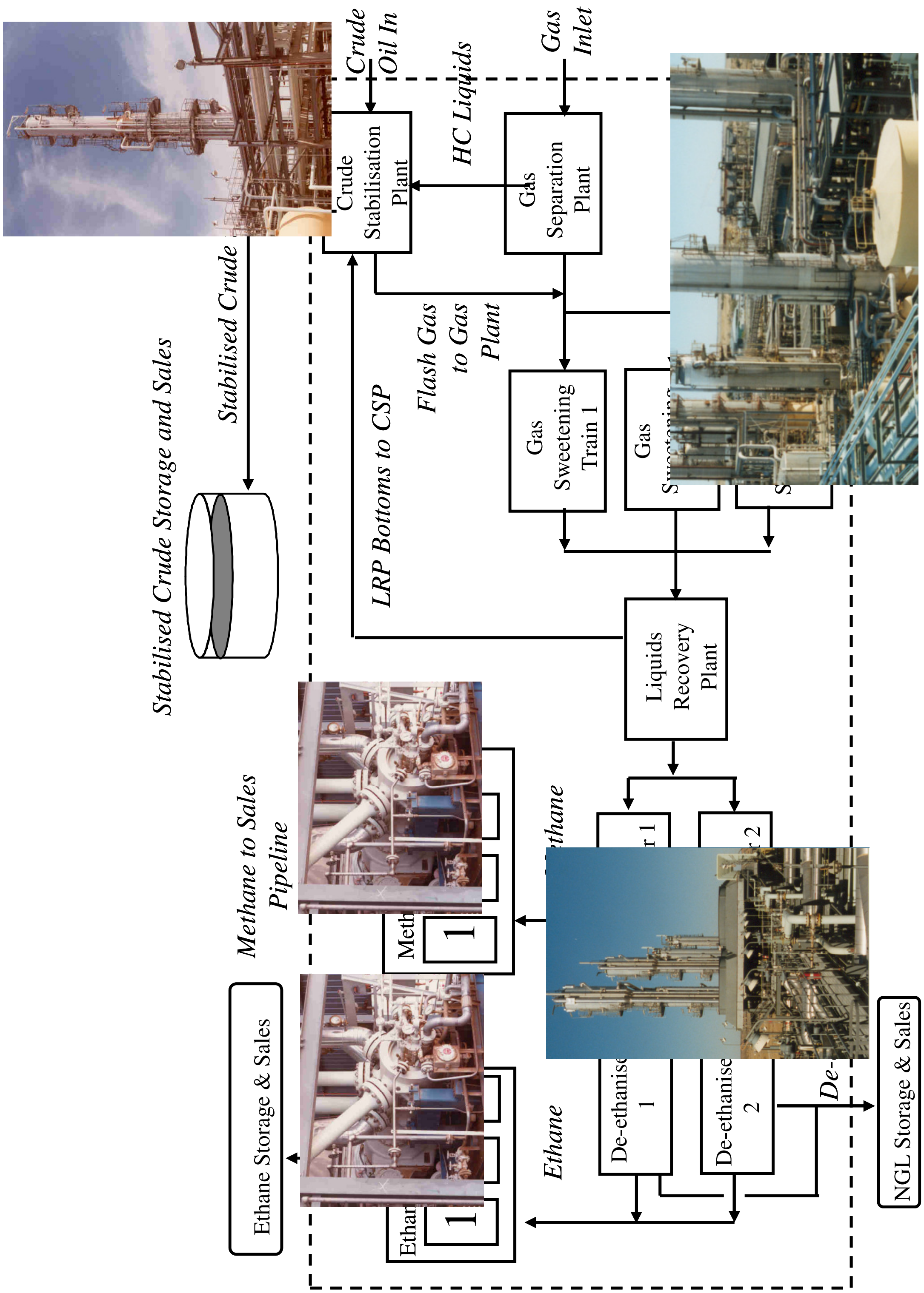


Figure 1.a. Gas Processing Schematic with photographs of key equipment

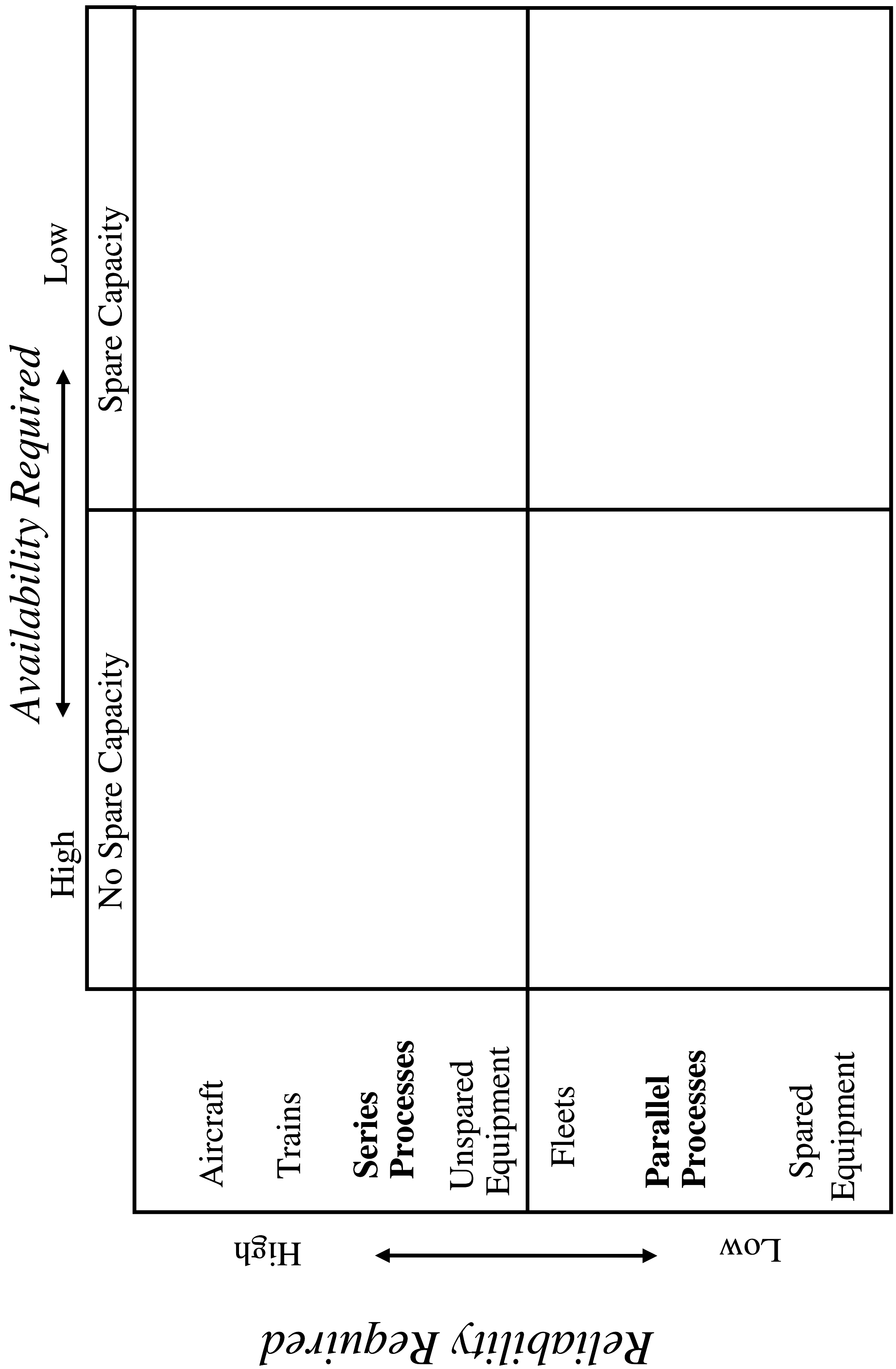


Exercise 1

Use the Strategy Matrix to determine the most appropriate maintenance organisational level policies/strategies to apply in each of the major areas of the plant.

Use the blank strategy matrix proforma and map the various plant areas to the matrix.

The Maintenance Management Strategy Matrix



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Exercise 2: The Crude Stabilisation Plant

Figure 2 shows the Crude Stabilisation Plant detail.

- The CSP has a single fractionation tower, which is fed through a feed heater and feed drum.
- A spared pump-set feed the CSP Tower. A spared pump-set also pumps the CSP bottoms (stabilised crude oil) to the Tank Farm.
- The CSP Tower can operate at 50% capacity without the Feed heater operational.
- CSP Flash gas is routed through a bank of 4 fin-fan type coolers, 3 of which must be operational or normal operations. The liquid condensate is recovered in Liquids Recovery Pot A and is refluxed back by way of a single Reflux Pump. Failure of the reflux system reduces tower capacity by 25%.
- The cooled flash gas is compressed using a spared compressor set, before being routed to a second back of 4 fin-fan coolers (3 of which must be operational) and a second reflux loop, with a Liquids Recovery pot and pump. This second reflux loop increases tower efficiency by an additional 5%.
- Heat is provided to the CSP Tower be way of 2 reboilers, each with their own reboiler pumps. The tower can operate at 80% capacity with a single reboiler operational.

Figure 2. Schematic Flow Diagram of Crude Stabilisation Plant

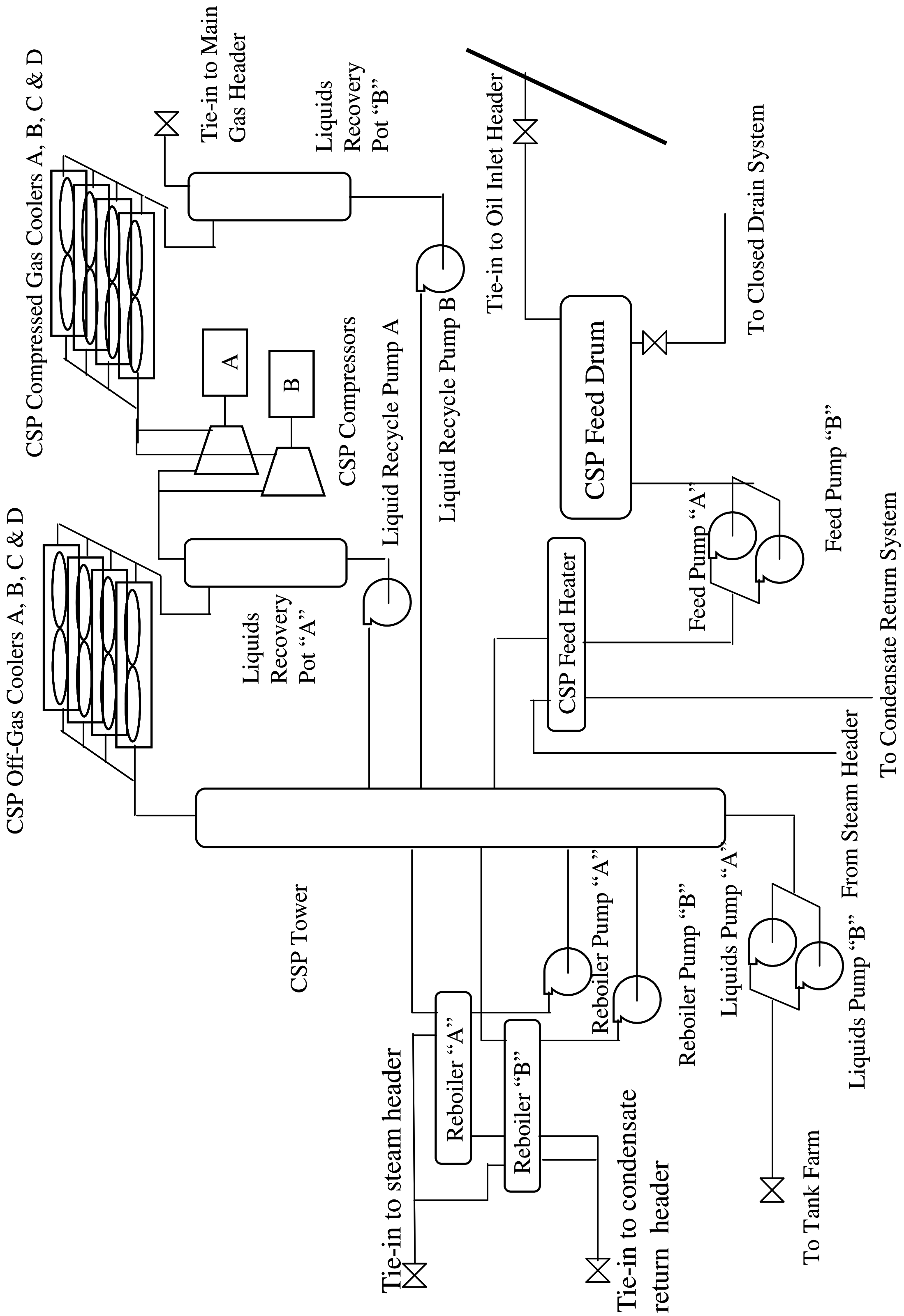

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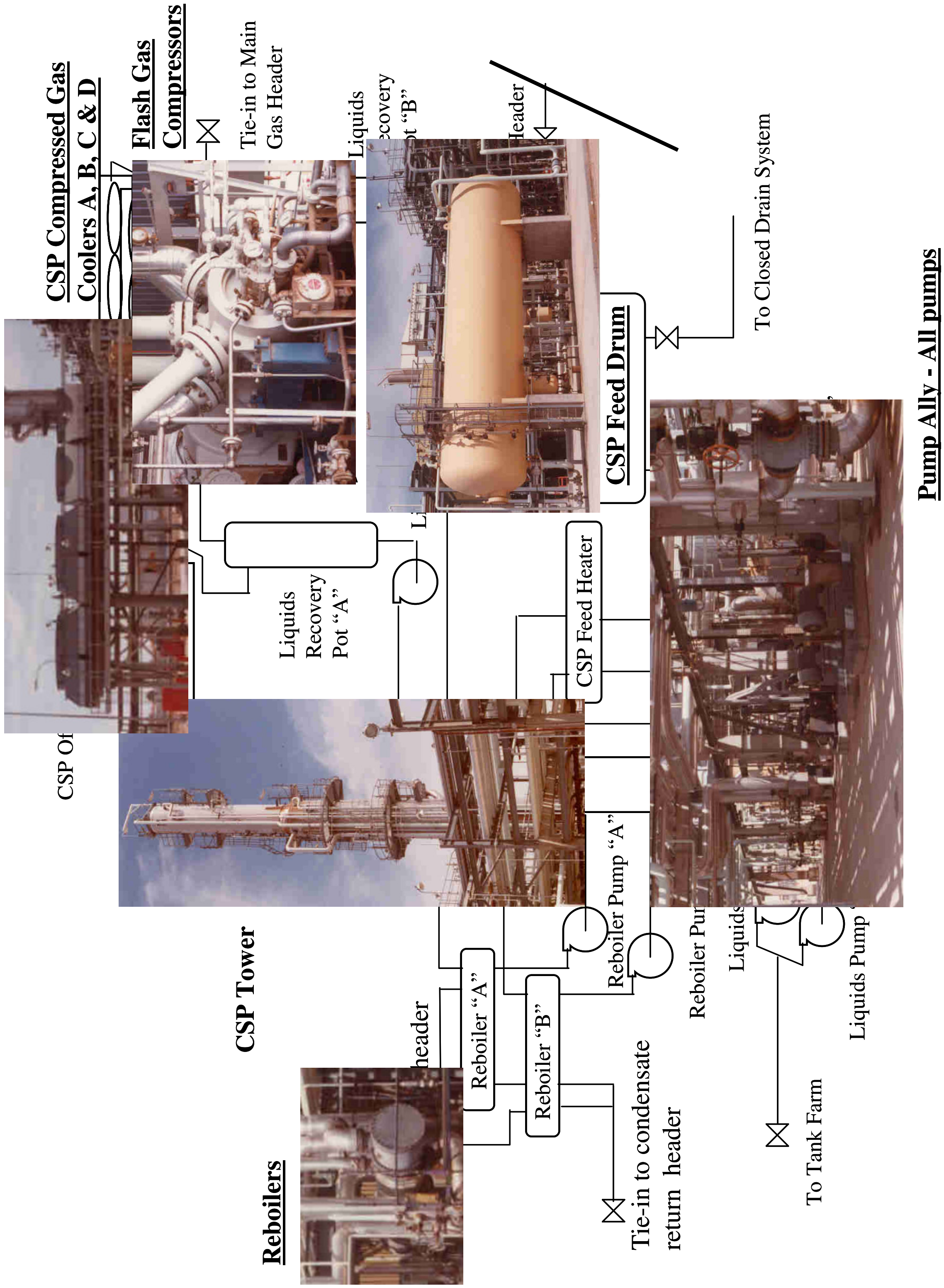
Figure 2.a. Schematic Flow Diagram of Crude Stabilisation Plant



Exercise 2: The Crude Stabilisation Plant

- Use the Maintenance Strategy Matrix to construct a "first draft" maintenance strategy proposal for each of the major units within the CSP;
- Map each of the major units in the CSP to the Strategy Matrix proforma.

The Maintenance Management Strategy Matrix

Availability Required

High ⟷ Low

Reliability Required		No Spare Capacity (High)	Spare Capacity (Low)
High	Aircraft Trains **Series Processes** Unspared Equipment		
Low	Fleets **Parallel Processes** Spared Equipment		

Outsourcing and Use of Contractors

Use of Contractors in Maintenance

Examples Include:-

- Using contractors to supplement permanent workforce;
- Using contractors for specific and specialist functions. eg. Condition Monitoring, Inspections, NDT etc.;
- Using contractors for specific projects eg. during turnarounds;
- Contracting out the whole maintenance function.

Typical uses of Contractors

Supplement workforce

- Contractors used to cover workload peaks;
- Contractor levels based on schedule requirements, derived from critical path;
- Needs driven;
- Paid on an hourly basis from timesheets - labour only.

Specialist Functions

- Contractors hire on a job-by-job or contract basis;
- Provide skills and expertise not available and/or not intended to be available in the permanent workforce;
- Often to cover jobs requiring significantly higher levels of skill than normally required and/or types of skills that are only occasionally required;
- Examples include: - Condition Monitoring, NDT, Airconditioning Tech, Scaffolding, Cleaning etc.

Specific Projects

- Contractors used for specific well defined projects or work package;
- Specific work packages defined from the overall Work Breakdown Structure allocated to contractors;
- Capital projects from Engineering Group

Outsourcing the whole maintenance function

- Most discussions of outsourcing centre around the definition of "core business" and outsourcing all that is "non-core";
- What is "core?"
- The answer is usually derived through political agenda's and short-term cost cutting justifications rather than through rational analysis.

Optimising Equipment Maintenance

Is Maintenance Core Business?

- Finding an answer is not easy. Need to consider many factors:
- Are skills general or equipment/plant specific;
- Level of planning and supervision that can be applied;
- Is learning specific or general;
- Are skills available in marketplace;
- Level of coordination required between maintenance and production;
- The nature of the contract.

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Issues to consider when allocating work to contractors?

- Are skills generic or equipment/plant specific;
- Level of planning and supervision that can be applied;
- Are skills available in marketplace;
- Level of coordination required between maintenance and production.

Contractor	Inhouse
Non-Specific	Specific
High / Low	Low
Readily Avail.	Not Readily Avail.
Low	High

 Slide 6

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Contracting/Outsourcing Costs

% of Maintenance Budget Spent on Contractors	% of Companies
• 2-5%	4%
• 5-10%	12.5%
• 10-20%	25%
• 20-35%	21%
• 35-50%	17%
• 50-75%	12.5%
• 75-10%	12%

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Contractor Tasks and Roles

Contractor Tasks/Activities	% of Companies
• Total Maintenance Service	14%
• Minor Capital Work	76%
• Labour Hire	76%
• NDT/Condition Monitoring	70%
• Shutdown Planning and Management	14%
• Offsite Overhauls and Repairs	72%
• Painting and Surface Protection	62%

Contractor Selection

- Ability of Contractor to supply good 1st-line Supervision;
- Important to supply regular/experienced employees vs new hire employees;
- Certify the contractors ability to supply appropriately experienced resources in the numbers required;
- Historical contractor safety and environment performance;

Evolution of approaches to Contracts

- Early 80's
- Late 80's
- 1992
- 1993/94
- 1995
- 1996

- Cost Plus
- Lump Sum
- Lump Sum contract negotiated Lump Sum for additional work;
- Lump Sum contract and 50% Lump Sum and 50% timesheets for all additional work;
- Lump sum contract & tendered billing rate timesheets for 80% additional work;
- Lump sum contract and fixed management fee for all additional work.

Reference: Ampol

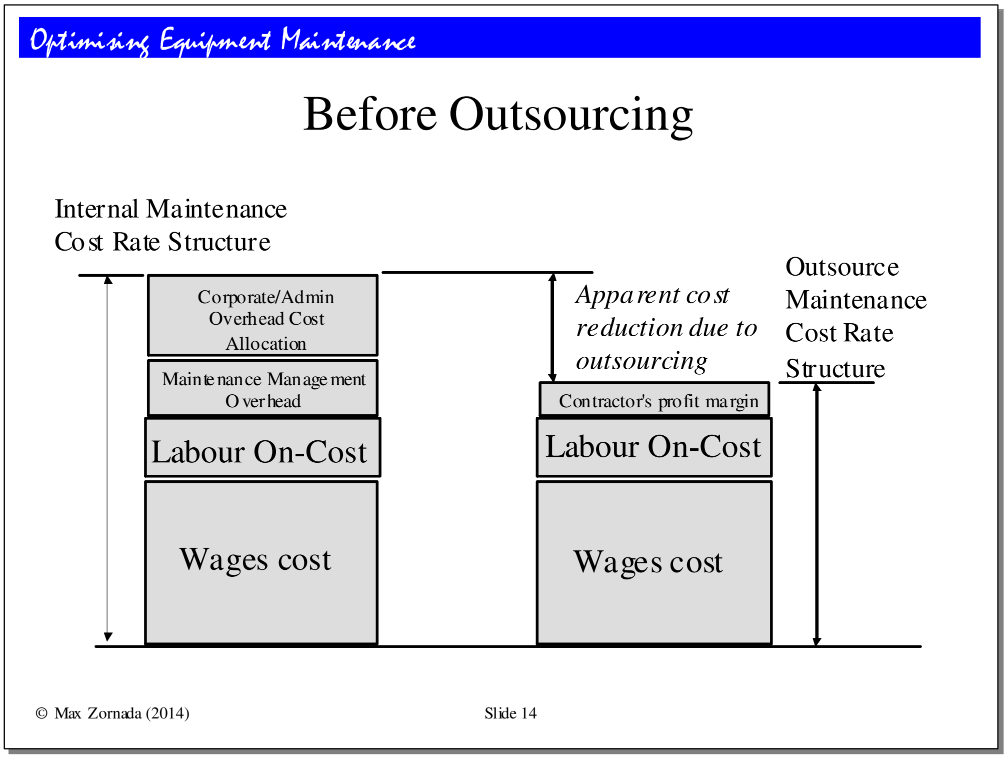
The Decision to Outsource

- The decision to outsource is usually made and justified on the basis of:
  - Simplifying management's workload, allowing them to focus better on core business;
  - Economic bases: - ie. cost reduction;
  - Resolving industrial relations issues.

Outsourcing Traps

Knowing your true costs

- A significant problem for many organisations when making an assessment of the economic benefit of outsourcing is calculating the benefit;
- A key issue is the difficulty in calculating the cost associated with not outsourcing;
- Cost accounting practices in many organisations give a distorted picture which discriminates against in-house maintenance when it may indeed be the superior option.


Optimising Equipment Maintenance
Before Outsourcing
Internal Maintenance
Cost Rate Structure
Corporate/Admin
Overhead Cost
Allocation
Maintenance Management
Overhead
Labour On-Cost
Wages cost
Apparent cost
reduction due to
outsourcing
Outsource
Maintenance
Cost Rate
Structure
Contractor's profit margin
Labour On-Cost
Wages cost
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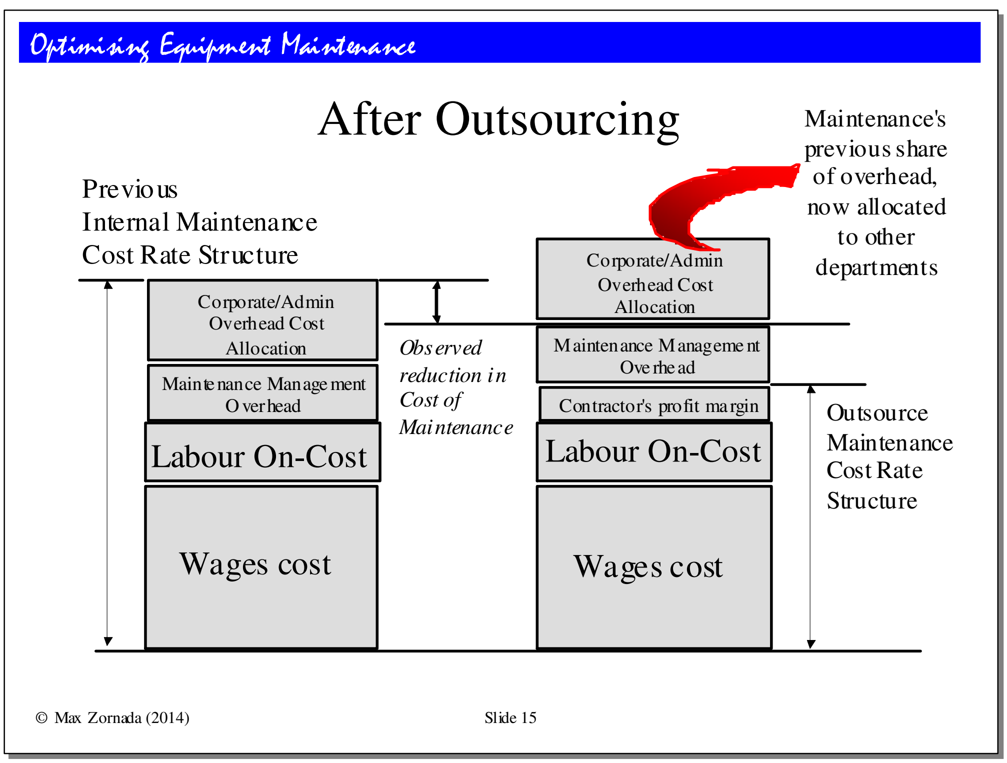
Optimising Equipment Maintenance
After Outsourcing
Maintenance's
previous share
of overhead,
now allocated
to other
departments
Previous
Internal Maintenance
Cost Rate Structure
Corporate/Admin
Overhead Cost
Allocation
Maintenance Management
Overhead
Labour On-Cost
Wages cost
Observed
reduction in
Cost of
Maintenance
Corporate/Admin
Overhead Cost
Allocation
Maintenance Management
Overhead
Contractor's profit margin
Labour On-Cost
Wages cost
Outsource
Maintenance
Cost Rate
Structure
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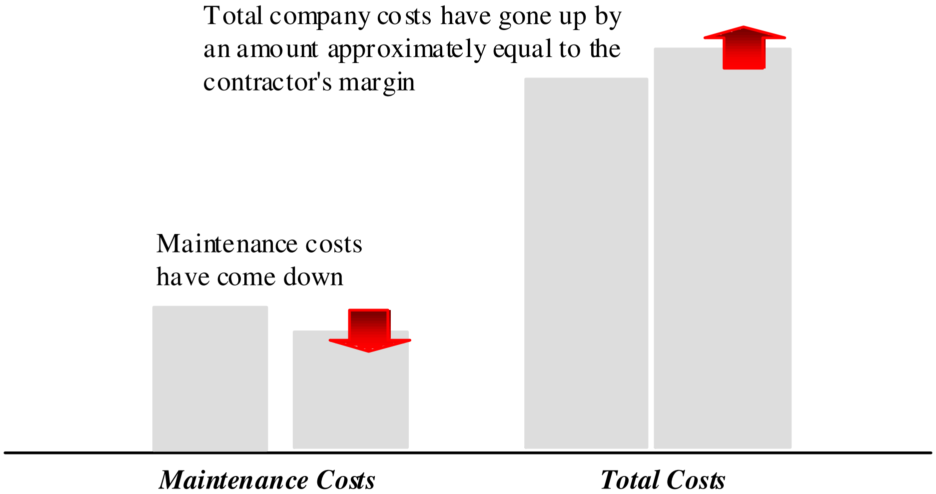
The Net Effect



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Outsourcing Lesson

- When calculating the cost/benefits of outsourcing, where outsourcing is being considered for mainly financial benefits:
  - Be sure you look at the "big picture" and take a total cost view;
  - Need to know:-
    - What costs will still remain in the company cost structure - even though they may no longer appear in the maintenance budget.

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Partnering

- Many organisations have elected to use a "partnering" approach, in order to avoid some of the negative aspects of using contractors;
- Establish a long term agreement with a contracting organisation and use them all of the time;
- Contractor retains a core of employees who are competent and become knowledgeable in the clients plant;
- Often use incentive type payment schemes to ensure contractor does not become complacent.

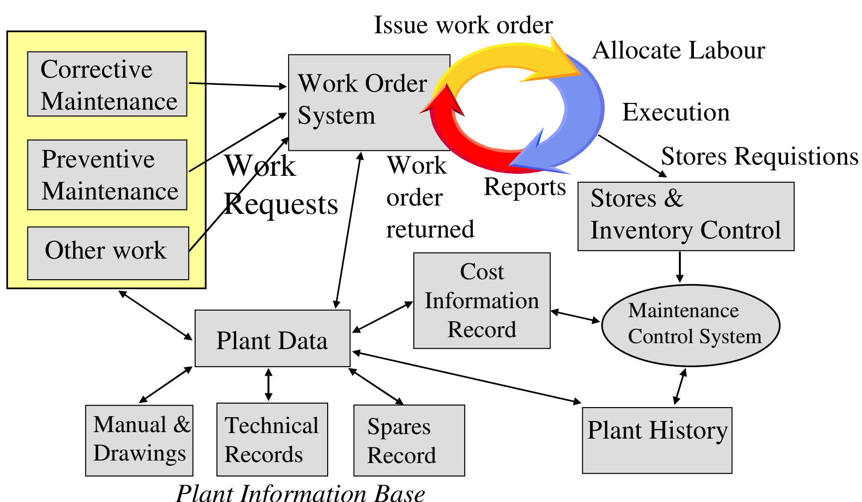
Module 6:

Computerised Maintenance Management Systems

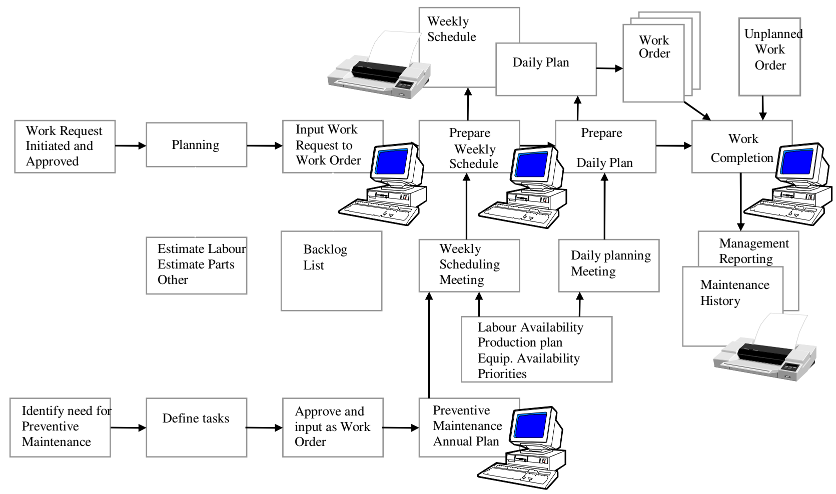
Computerised Maintenance Management Systems (CMMS) and Maintenance Work Order System Design

Maintenance Documentation Model

(Kelly and Harris, 1978)



Maintenance Management System Work Flows



Optimising Equipment Maintenance

Maintenance Work Request - Sample

MAINTENANCE WORK REQUEST — No: 11701

Area *Crude Stabilisation Plant* — Equip. No. *P-60-10A*

Equipment Description *Reboiler Pump*

Description of Symptom
Pump doesn't work properly. Is not pumping at specified rate. Check and repair as required.

Work Type	
Routine	
Unit Offline	✓
Major Shut	
Other	

Work Done for Urgent Work

PRIORITY			
1	2	3	Safety
	✓		

Accounting Cost Code

Originator C. Perrett — Date: 14/6/2012

Approval *R. Millar* — Date: *14/6/2012*

Craft Code								Duration	Work Group Code
Estimated Time									

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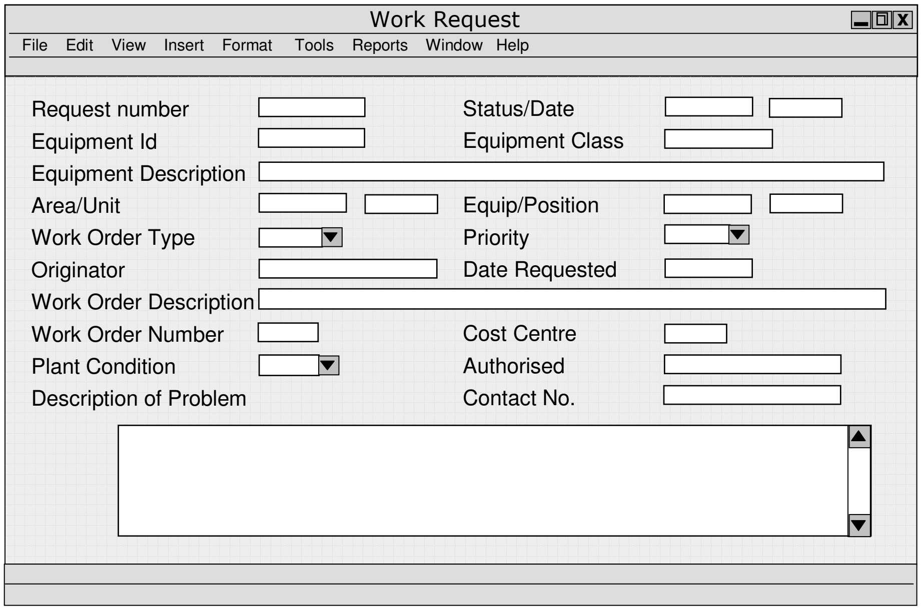

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Optimising Equipment Maintenance

Work Initiation - Key Issues

- Equipment identification
- Priority System
- Work type definition
- Initiation
- Authorisation

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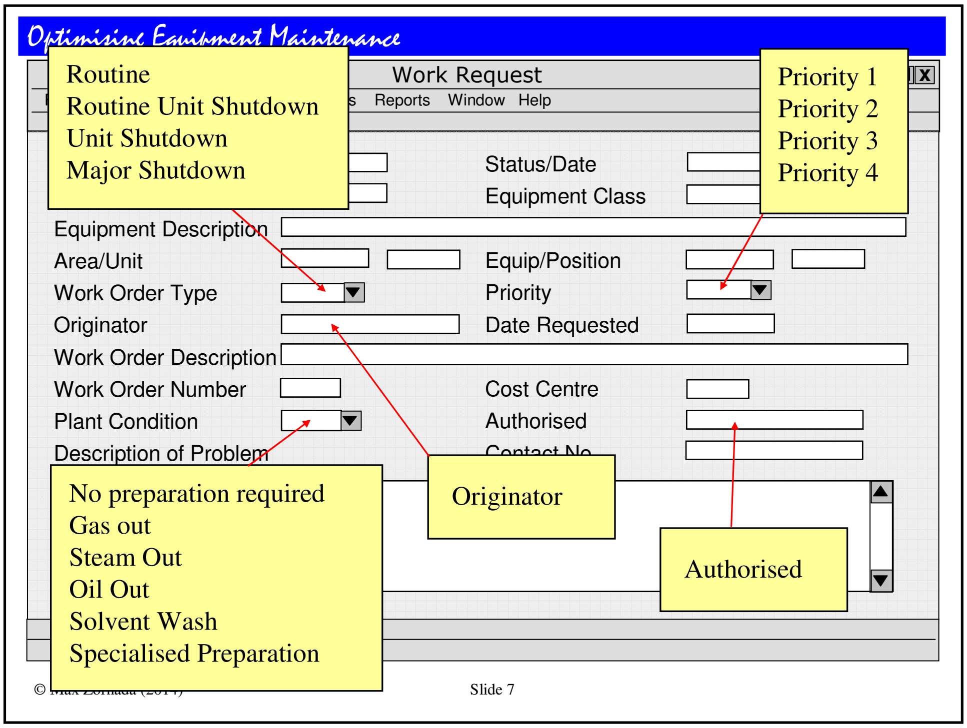

Optimising Equipment Maintenance

Exercise: How does your organisation handle

Issue	Your organisation's approach
Equipment Identification	
Priority System	
Work Type Definitions	
Initiation of Work Requests	
Authorisation of Work	

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Priorities - How one company does it ..

- Priority 1: Work will start ASAP, even if it means interrupting scheduled work. Priority 1 will only be allocated to jobs currently affecting output needed for immediate sales. Work on equipment that has spare capacity is never priority 1.
- Priority 2: Work which must be carried out within the current weekly schedule period. If not carried out in the current schedule period:
  - There is a high risk that production will be affected;
  - The equipment, while continuing to operate will continue to deteriorate and cause increased maintenance costs if repairs are delayed.
- Priority 3: Work that will be scheduled as part of the the next weekly scheduling process. PM is the most important category of this type of work.
- Priority 4: Work that needs to be done but which is independent of production requirements.

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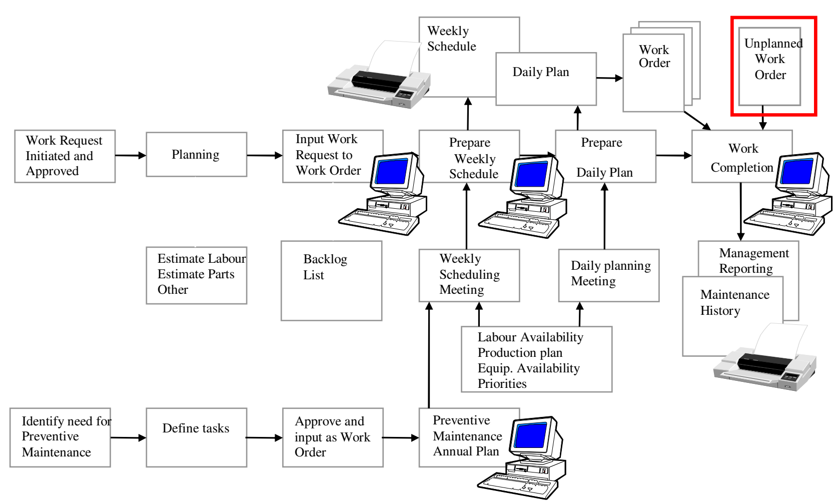
Maintenance Management System Work Flows



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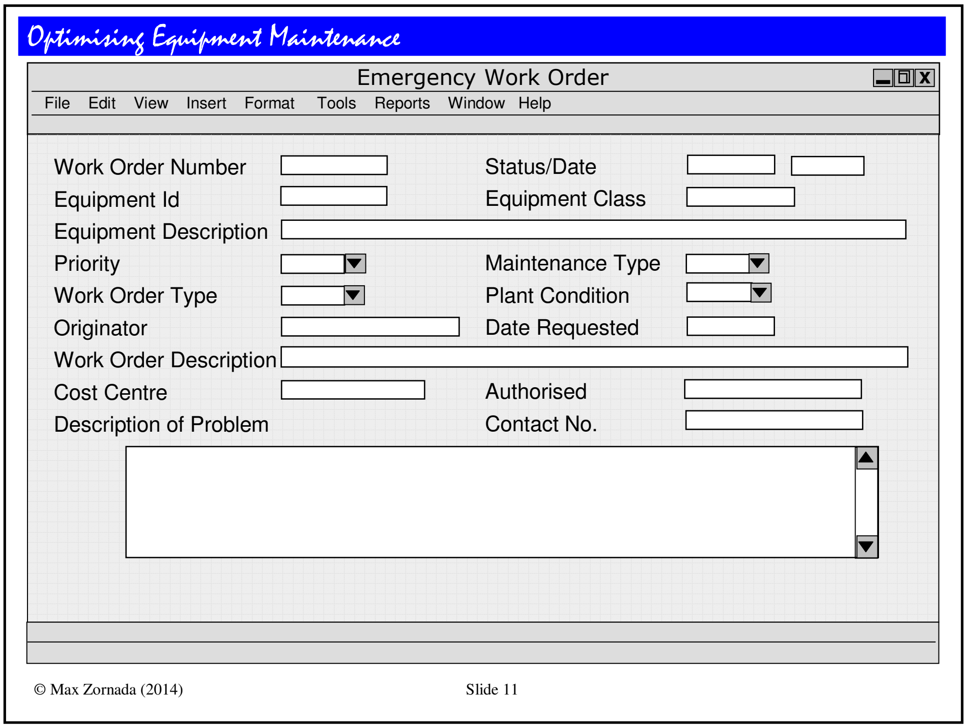
Optimising Equipment Maintenance
Emergency Work Order
File Edit View Insert Format Tools Reports Window Help
Work Order Number
Status/Date
Equipment Id
Equipment Class
Equipment Description
Priority
Maintenance Type
Work Order Type
Plant Condition
Originator
Date Requested
Work Order Description
Cost Centre
Authorised
Description of Problem
Contact No.
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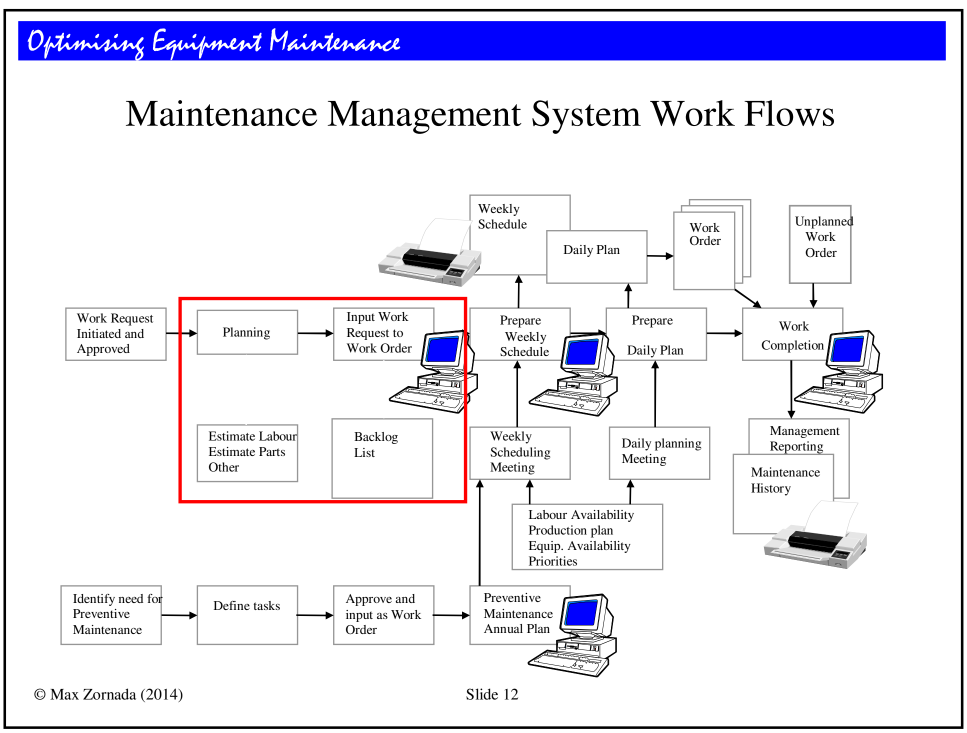
Optimising Equipment Maintenance
Maintenance Management System Work Flows
Weekly Schedule
Daily Plan
Work Order
Unplanned Work Order
Work Request Initiated and Approved
Planning
Input Work Request to Work Order
Prepare Weekly Schedule
Prepare Daily Plan
Work Completion
Estimate Labour Estimate Parts Other
Backlog List
Weekly Scheduling Meeting
Daily planning Meeting
Management Reporting
Maintenance History
Labour Availability Production plan Equip. Availability Priorities
Identify need for Preventive Maintenance
Define tasks
Approve and input as Work Order
Preventive Maintenance Annual Plan
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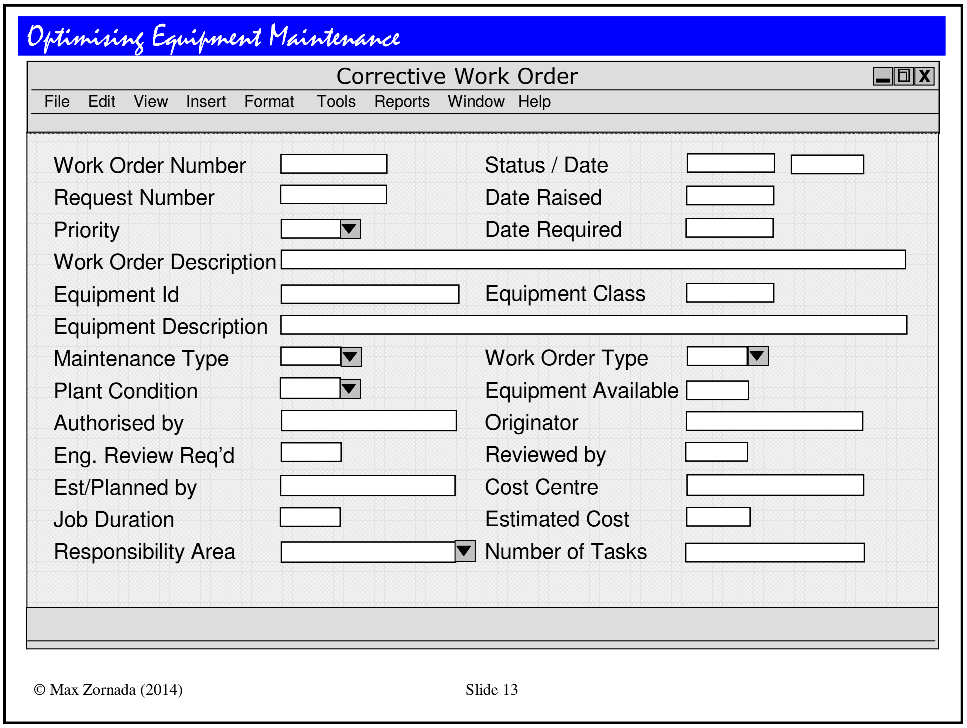
Optimising Equipment Maintenance
Corrective Work Order
File Edit View Insert Format Tools Reports Window Help
Work Order Number
Request Number
Priority
Work Order Description
Equipment Id
Equipment Description
Maintenance Type
Plant Condition
Authorised by
Eng. Review Req'd
Est/Planned by
Job Duration
Responsibility Area
Status / Date
Date Raised
Date Required
Equipment Class
Work Order Type
Equipment Available
Originator
Reviewed by
Cost Centre
Estimated Cost
Number of Tasks
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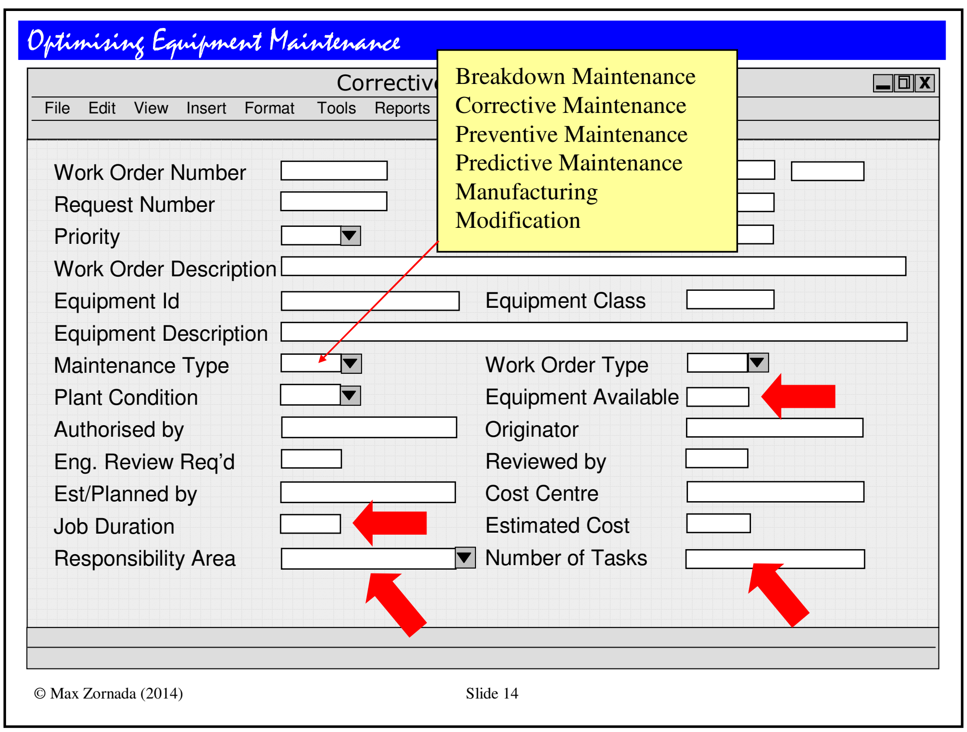
Optimising Equipment Maintenance
Corrective
File Edit View Insert Format Tools Reports
Breakdown Maintenance
Corrective Maintenance
Preventive Maintenance
Predictive Maintenance
Manufacturing
Modification
Work Order Number
Request Number
Priority
Work Order Description
Equipment Id
Equipment Description
Maintenance Type
Plant Condition
Authorised by
Eng. Review Req'd
Est/Planned by
Job Duration
Responsibility Area
Equipment Class
Work Order Type
Equipment Available
Originator
Reviewed by
Cost Centre
Estimated Cost
Number of Tasks
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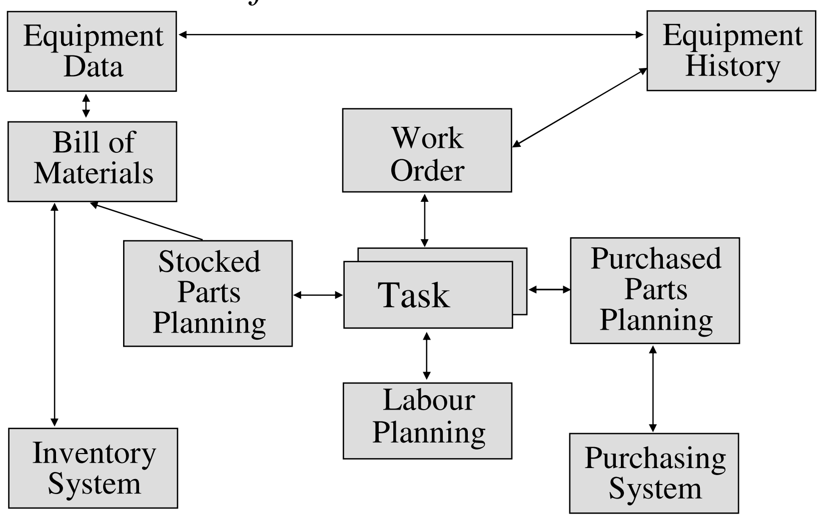
Slide 14

Optimising Equipment Maintenance

Work Order Planning

Information Structure



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Optimising Equipment Maintenance

Discussion Issues

- Multiple tasks per work order;
- Joint responsibility for work orders;
  - e.g. Mechanical and Electrical etc.
- Tracking partial completion of jobs for long jobs.

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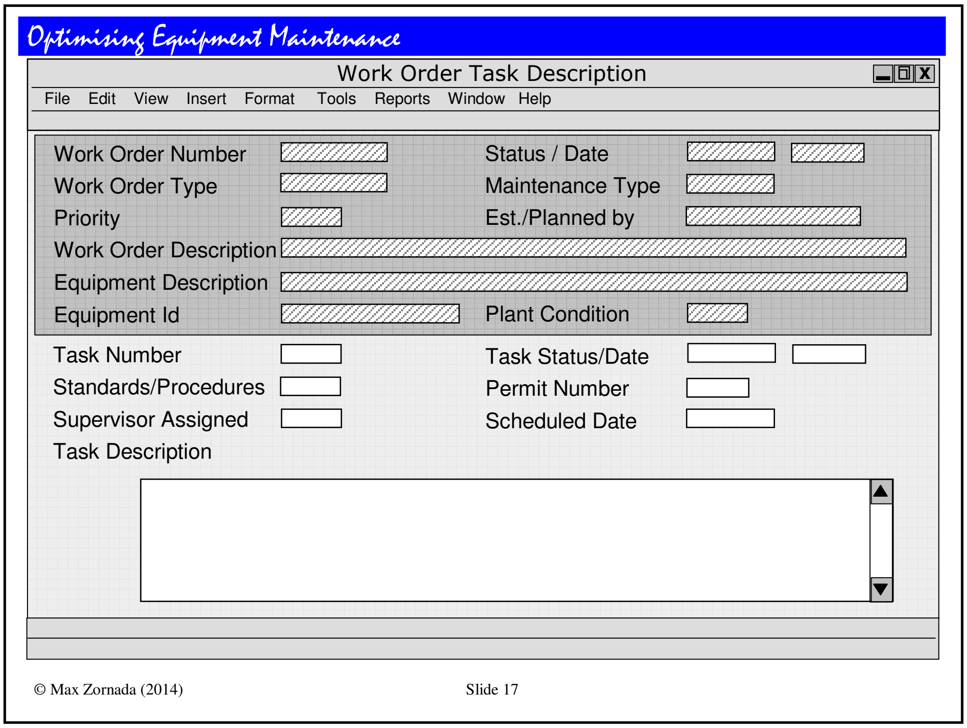
Optimising Equipment Maintenance
Work Order Task Description
File Edit View Insert Format Tools Reports Window Help
Work Order Number
Status / Date
Work Order Type
Maintenance Type
Priority
Est./Planned by
Work Order Description
Equipment Description
Equipment Id
Plant Condition
Task Number
Task Status/Date
Standards/Procedures
Permit Number
Supervisor Assigned
Scheduled Date
Task Description
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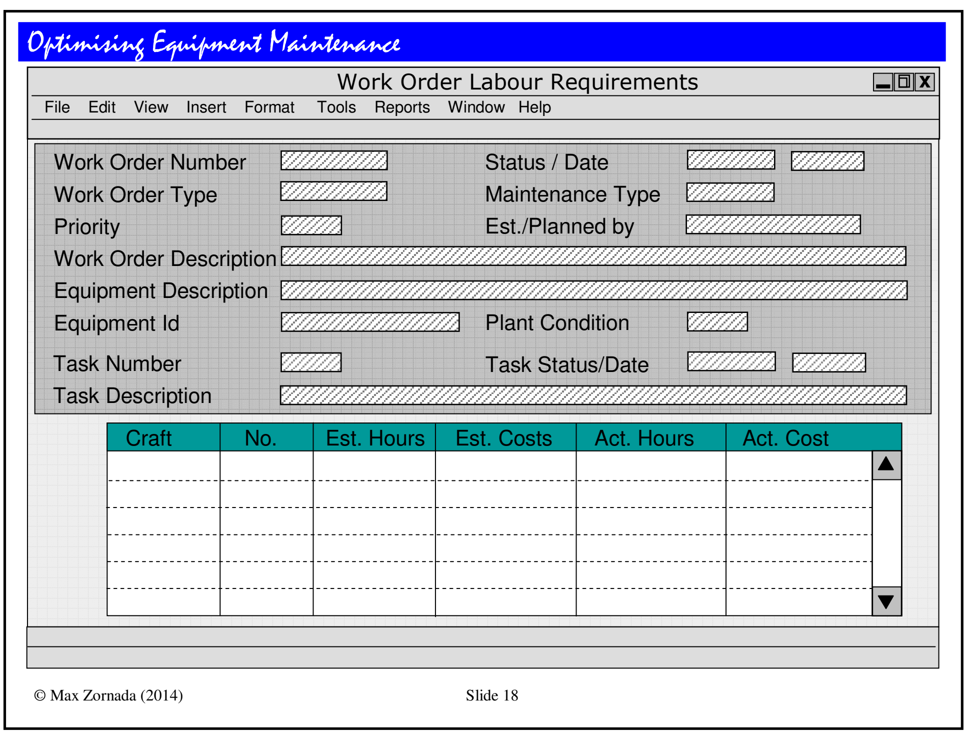
Optimising Equipment Maintenance
Work Order Labour Requirements
File Edit View Insert Format Tools Reports Window Help
Work Order Number
Status / Date
Work Order Type
Maintenance Type
Priority
Est./Planned by
Work Order Description
Equipment Description
Equipment Id
Plant Condition
Task Number
Task Status/Date
Task Description
Craft
No.
Est. Hours
Est. Costs
Act. Hours
Act. Cost
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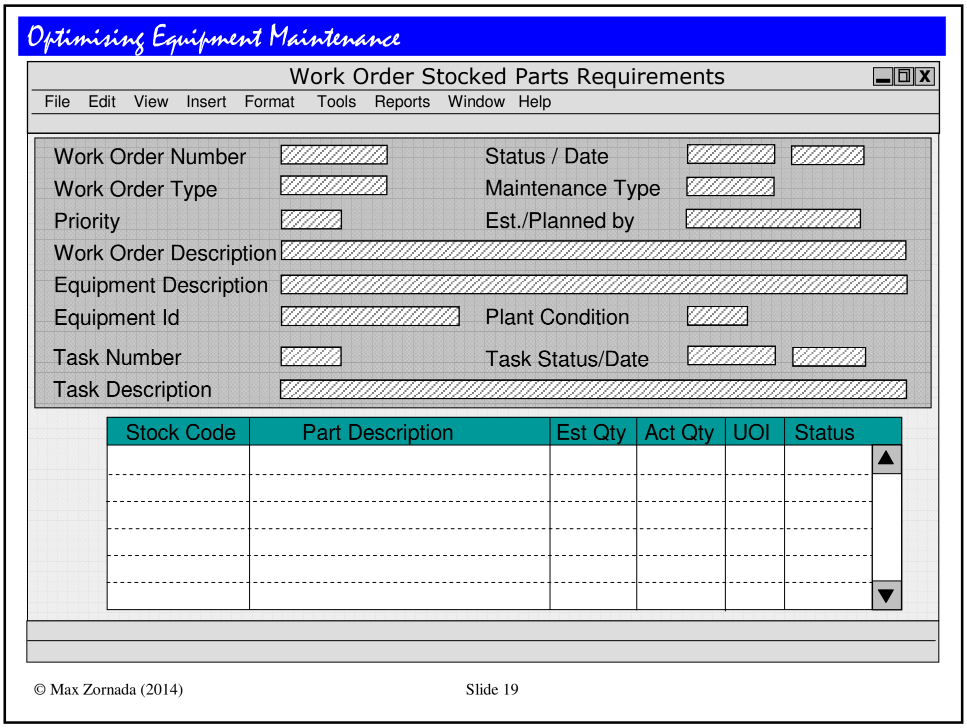
Optimising Equipment Maintenance
Work Order Stocked Parts Requirements
File Edit View Insert Format Tools Reports Window Help
Work Order Number
Status / Date
Work Order Type
Maintenance Type
Priority
Est./Planned by
Work Order Description
Equipment Description
Equipment Id
Plant Condition
Task Number
Task Status/Date
Task Description
Stock Code
Part Description
Est Qty
Act Qty
UOI
Status
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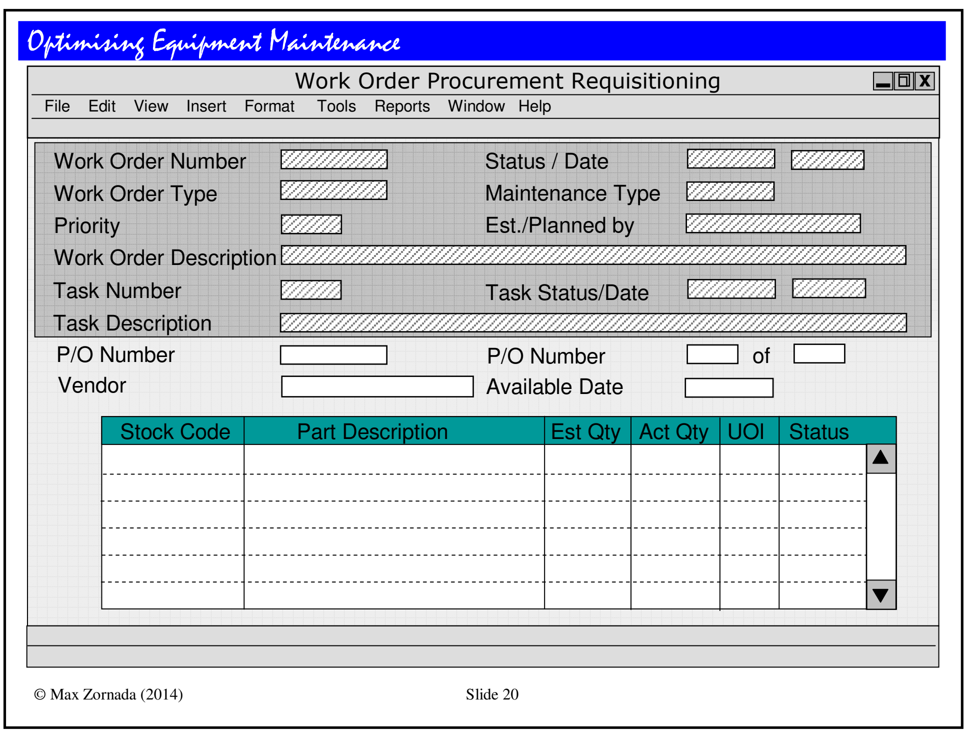
Optimising Equipment Maintenance
Work Order Procurement Requisitioning
File Edit View Insert Format Tools Reports Window Help
Work Order Number
Status / Date
Work Order Type
Maintenance Type
Priority
Est./Planned by
Work Order Description
Task Number
Task Status/Date
Task Description
P/O Number
P/O Number
of
Vendor
Available Date
Stock Code
Part Description
Est Qty
Act Qty
UOI
Status
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Optimising Equipment Maintenance

Work Standards and Procedures

File Edit View Insert Format Tools Reports Window Help

Std/Procedure Number

Permit Reference

Maintenance Type

Equipment Class

Short Description

Step	Procedure Description

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Optimising Equipment Maintenance

Bill of Materials

File Edit View Insert Format Tools Reports Window Help

Equipment Class

Last Update

BOM Description

Manufacturer

Model Number

Revision Number

Number of Levels

Item	Stock Code	Part Description	P/A	UOI	Qty Req

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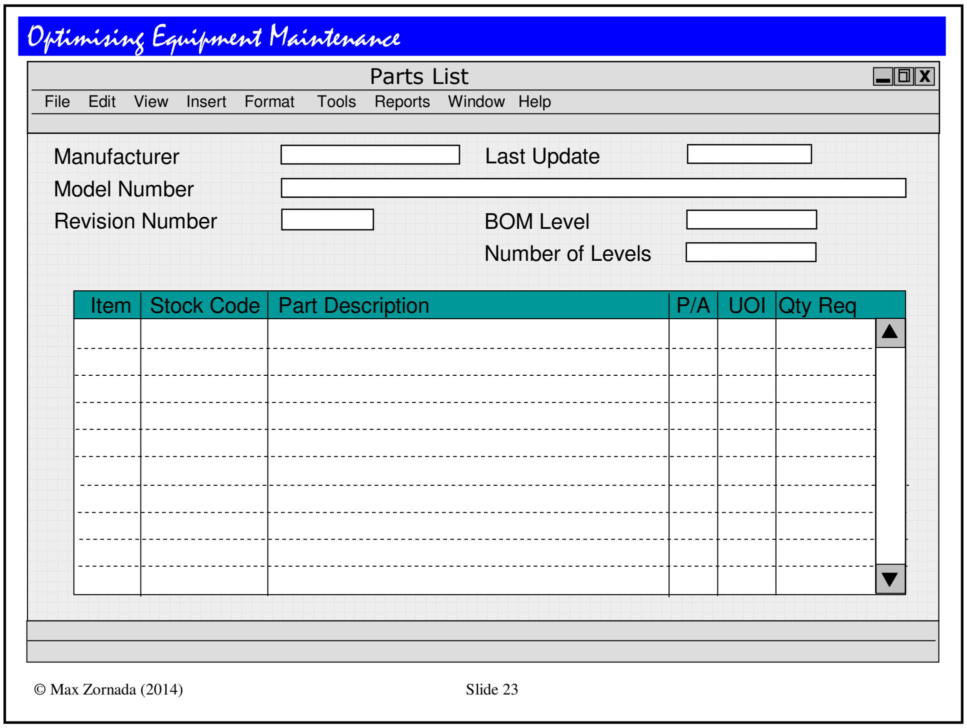

Optimising Equipment Maintenance
Parts List
File Edit View Insert Format Tools Reports Window Help
Manufacturer
Last Update
Model Number
Revision Number
BOM Level
Number of Levels
Item
Stock Code
Part Description
P/A
UOI
Qty Req
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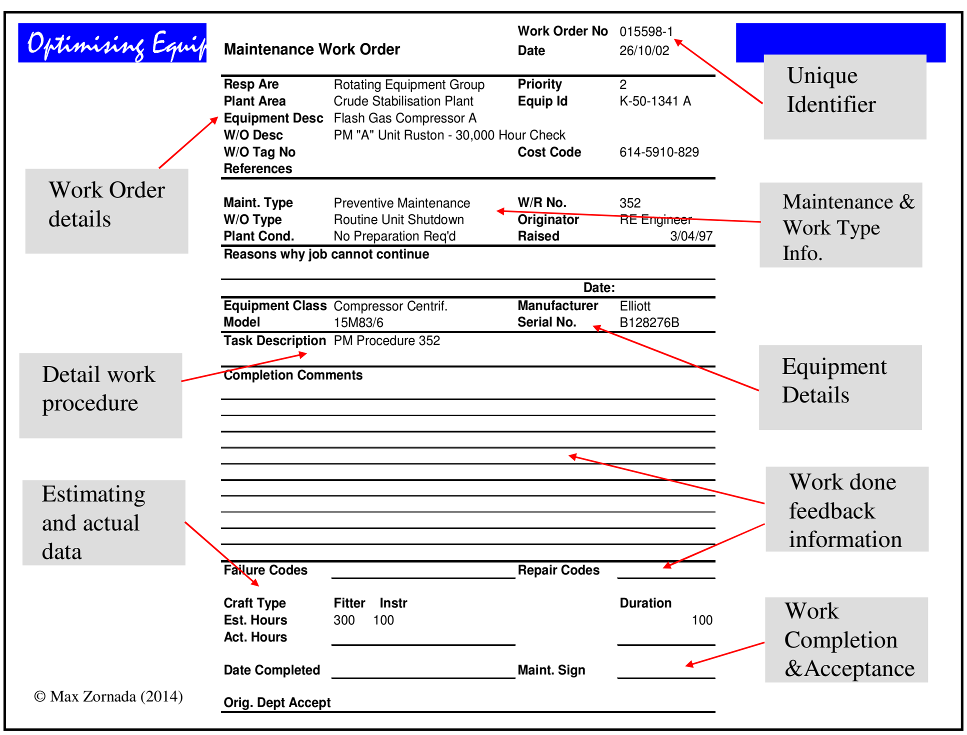

Optimising Equip
Maintenance Work Order
Work Order No 015598-1
Date 26/10/02
Resp Are Rotating Equipment Group
Priority 2
Plant Area Crude Stabilisation Plant
Equip Id K-50-1341 A
Equipment Desc Flash Gas Compressor A
W/O Desc PM "A" Unit Ruston - 30,000 Hour Check
W/O Tag No
Cost Code 614-5910-829
References
Maint. Type Preventive Maintenance
W/R No. 352
W/O Type Routine Unit Shutdown
Originator RE Engineer
Plant Cond. No Preparation Req'd
Raised 3/04/97
Reasons why job cannot continue
Date:
Equipment Class Compressor Centrif.
Manufacturer Elliott
Model 15M83/6
Serial No. B128276B
Task Description PM Procedure 352
Completion Comments
Failure Codes
Repair Codes
Craft Type Fitter Instr
Duration
Est. Hours 300 100
100
Act. Hours
Date Completed
Maint. Sign
Orig. Dept Accept
Unique Identifier
Work Order details
Maintenance & Work Type Info.
Detail work procedure
Equipment Details
Estimating and actual data
Work done feedback information
Work Completion &Acceptance
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Optimising Equi

Standard Procedure M0352

Maintenance Procedure

	O.K.	Note
1 Carry out flame failure test procedure. Ruston TB-6G2C-135 Item 4	( )	( )
2 Repack auxilliary electric motor bearings	( )	( )
3 Check all pumps for noisy operation	( )	( )
4 Inspect all couplings	( )	( )
5 Repack and overhaul as necessary	( )	( )
6 Check physical condition and carry out insulation test on	( )	( )
7 Ignition leads. Minimum 100 M Ohms on 500 V Megger Replace as necessay.	( )	( )
8 Change out ignition plugs	( )	( )
9 Check all solenoid valves for leakage and correct operation	( )	( )
9.1 Sol 1 : Igniter Gas	( )	( )
9.2 Sol 2: Starter engagement	( )	( )
9.3 Sol 31, 3B, 4A, 4B: Blow off valves	( )	( )
9.4 Sol 5: Main Fuel Gas	( )	( )
9.5 Sol 7: Pilot Slam Shut	( )	( )
10 Carry out end-to-end operational check of the engine air inlet duct and filtration system See Donaldson TTD information contained in LRP Mechanical Catalogue Volume 3 Section A-2	( )	( )
11 Carry out alignment check between engine and driven machine. Compare with required alignment readings held by Rotating Equipment Supervisor. Adjust as necessary.	( )	( )
12 In conjunction with combuster inpection, carry out borescope inspection.	( )	( )
13 Carry out in-situ visual inspection of the main gera box internals (Ruston TB-6A3-1) for wear and contamination.	( )	( )
14 Carry out a complete governor calibration	( )	( )
Ruston TB-6G3B-1C	( )	( )
Ruston TB-6G3C-94	( )	( )

Notes:

Procedure continued on next page Page 1 or 7

Unique Identifier

Detail work procedure

Step completed check

Feedback information & Notes

Optimising Equipment Maintenance

Work Order Scheduling

File Edit View Insert Format Tools Reports Window Help

Schedule Date

Responsibility Area

Craft Code

Available Hours

% Assigned

W/O	Task	Description	Status	Tot Hrs	% Sched

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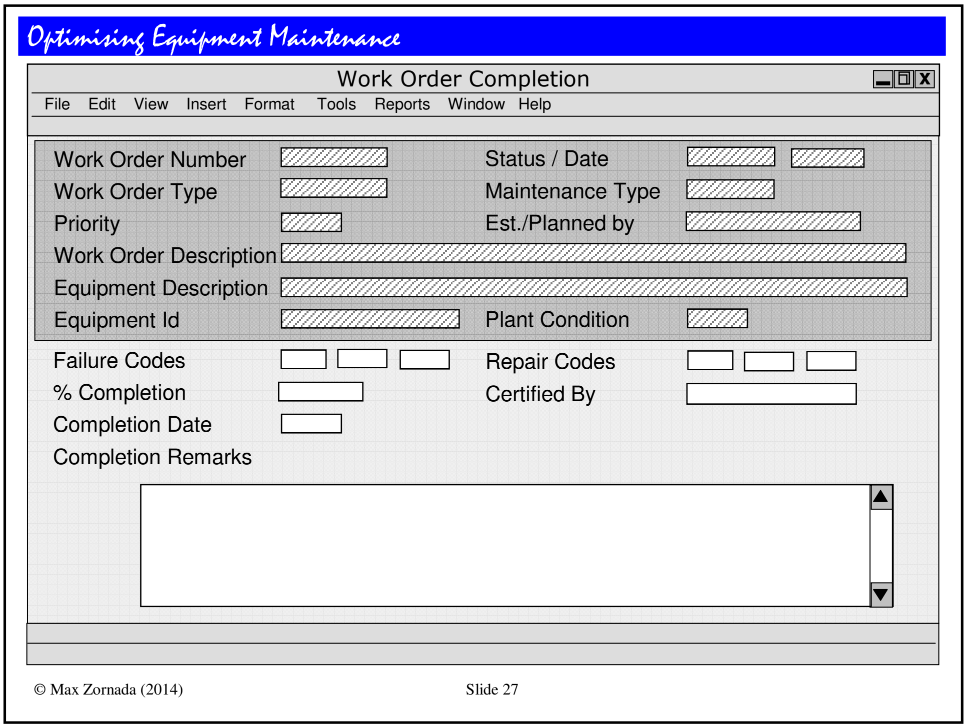
Optimising Equipment Maintenance
Work Order Completion
File Edit View Insert Format Tools Reports Window Help
Work Order Number
Status / Date
Work Order Type
Maintenance Type
Priority
Est./Planned by
Work Order Description
Equipment Description
Equipment Id
Plant Condition
Failure Codes
Repair Codes
% Completion
Certified By
Completion Date
Completion Remarks
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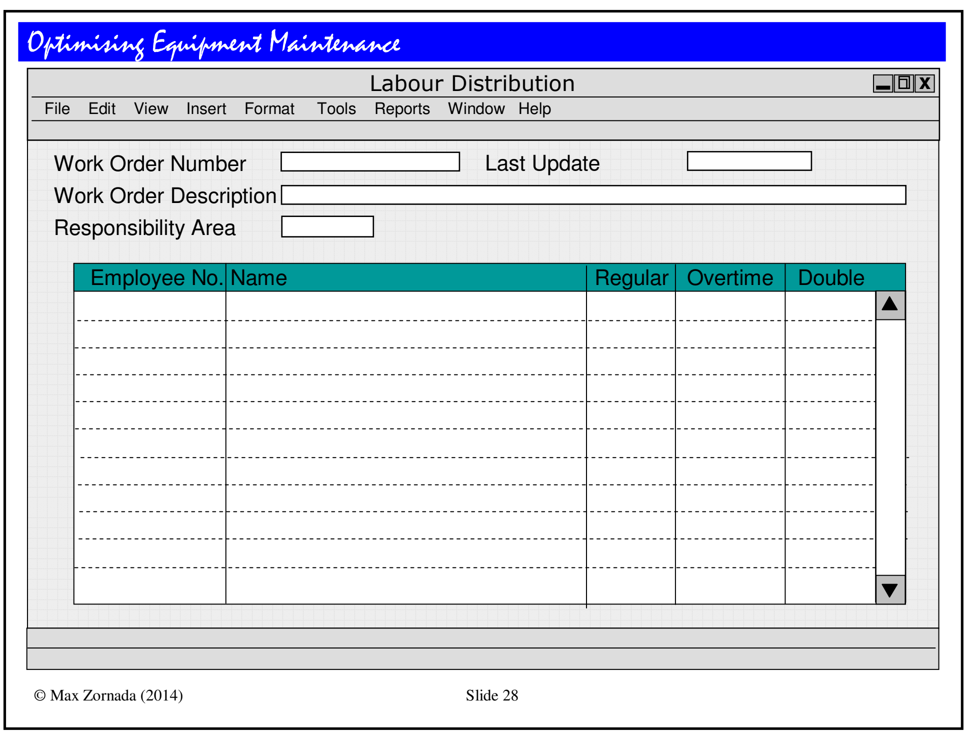
Optimising Equipment Maintenance
Labour Distribution
File Edit View Insert Format Tools Reports Window Help
Work Order Number
Last Update
Work Order Description
Responsibility Area
Employee No.
Name
Regular
Overtime
Double
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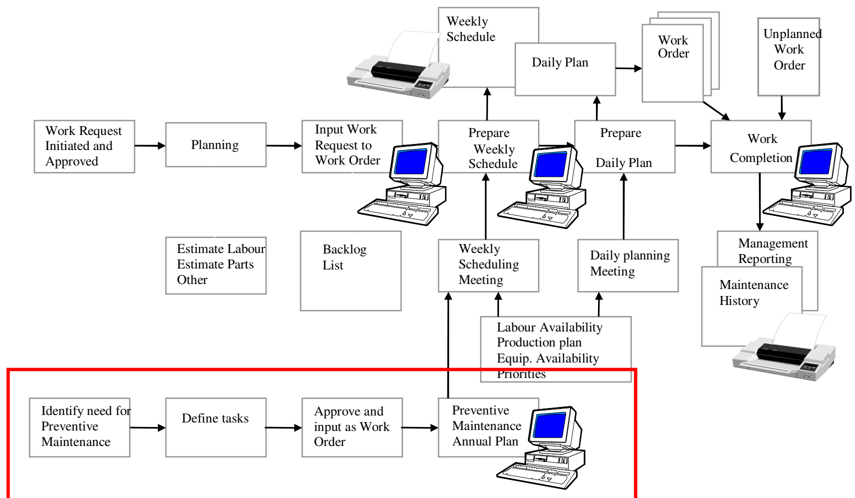
Optimising Equipment Maintenance

Maintenance Management System Work Flows



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Optimising Equipment Maintenance

Preventive Work Order

File Edit View Insert Format Tools Reports Window Help

Work Order Number		Status / Date	
Request Number		Date Raised	
Priority		Date Required	
Work Order Description			
Equipment Id		Equipment Class	
Equipment Description			
Maintenance Type		Work Order Type	
Plant Condition		Equipment Available	
PM Last Done		PM Type	
Next Scheduled		Schedule Interval	
Authorised by		Originator	
Est/Planned by		Cost Centre	
Job Duration		Estimated Cost	
Responsibility Area		Number of Tasks	

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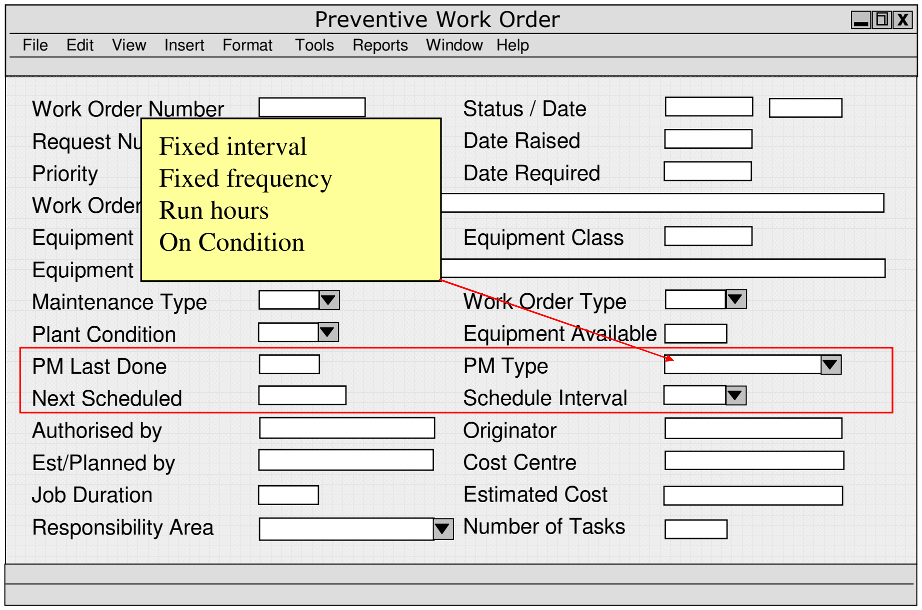
Optimising Equipment Maintenance



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Optimising Equipment Maintenance

Exercise: How does your organisation handle

Issue	Your organisation's approach
Scheduling and Issue of Work	
Registering of Completed Work	
Management of PM Work	
Emergency work	
Supervisory Responsibility	

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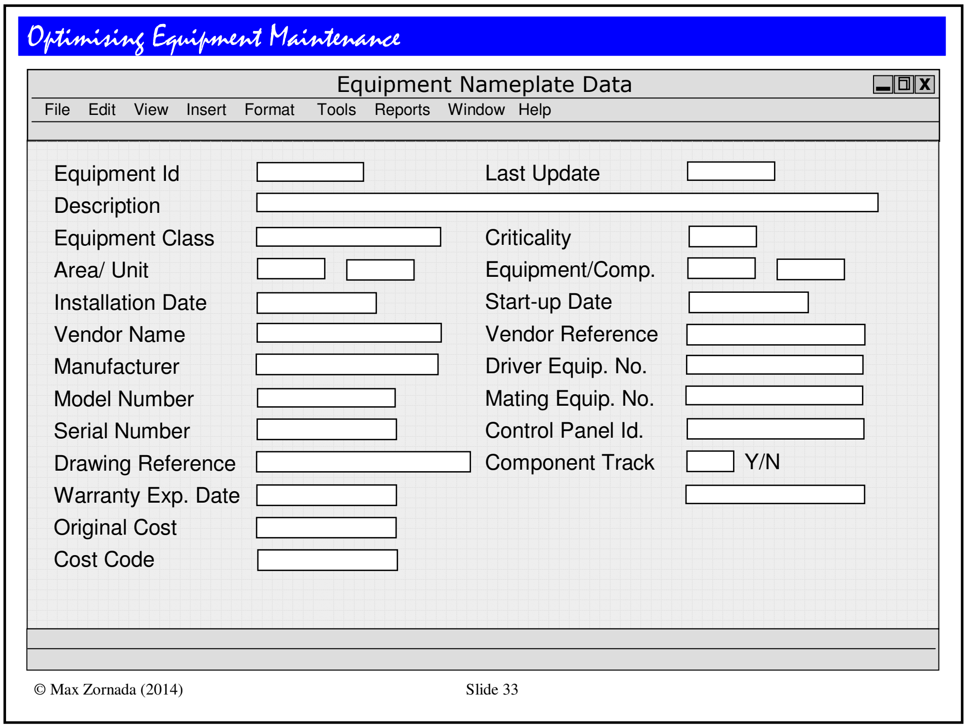
Optimising Equipment Maintenance
Equipment Nameplate Data
File Edit View Insert Format Tools Reports Window Help
Equipment Id
Last Update
Description
Equipment Class
Criticality
Area/ Unit
Equipment/Comp.
Installation Date
Start-up Date
Vendor Name
Vendor Reference
Manufacturer
Driver Equip. No.
Model Number
Mating Equip. No.
Serial Number
Control Panel Id.
Drawing Reference
Component Track
Y/N
Warranty Exp. Date
Original Cost
Cost Code
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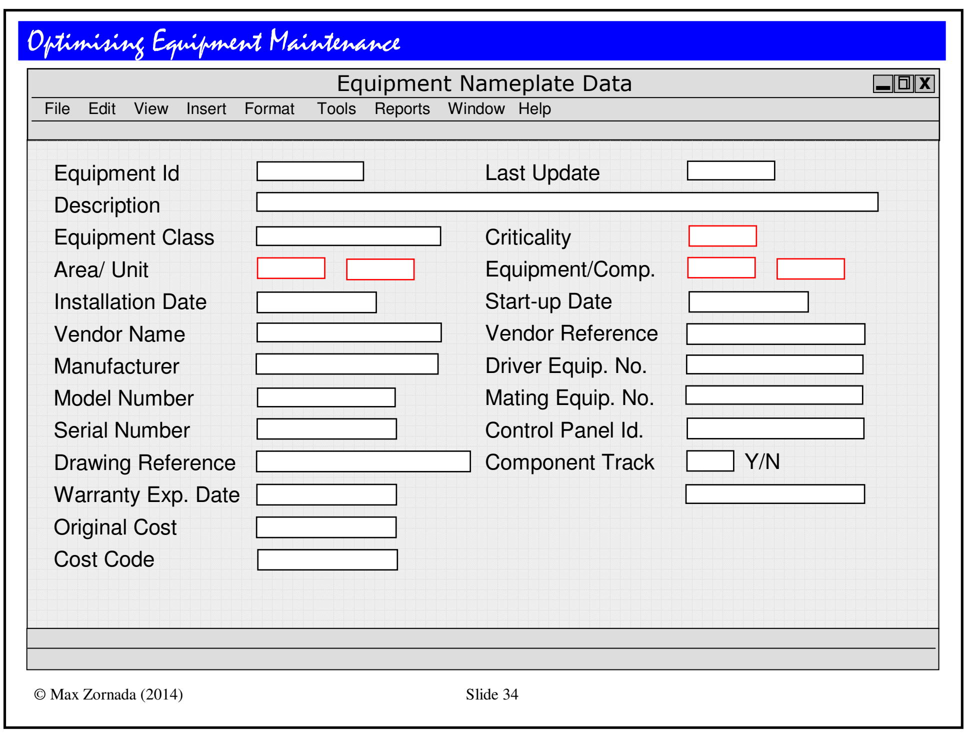
Optimising Equipment Maintenance
Equipment Nameplate Data
File Edit View Insert Format Tools Reports Window Help
Equipment Id
Last Update
Description
Equipment Class
Criticality
Area/ Unit
Equipment/Comp.
Installation Date
Start-up Date
Vendor Name
Vendor Reference
Manufacturer
Driver Equip. No.
Model Number
Mating Equip. No.
Serial Number
Control Panel Id.
Drawing Reference
Component Track
Y/N
Warranty Exp. Date
Original Cost
Cost Code
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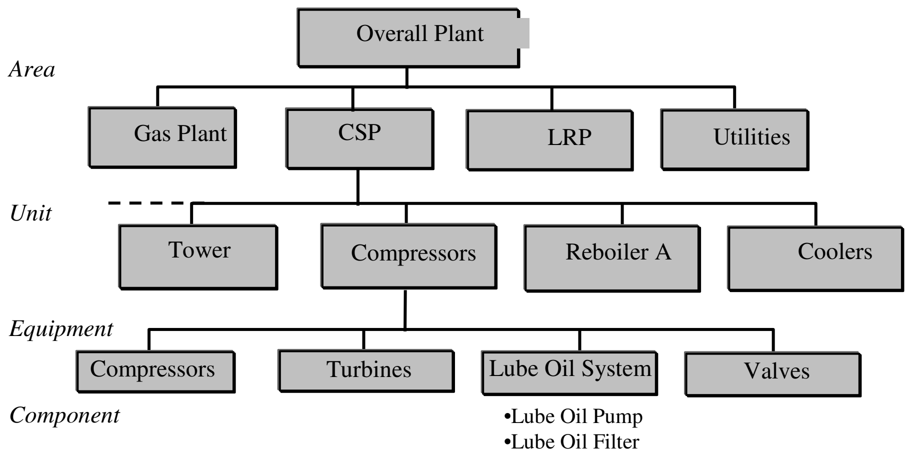
Optimising Equipment Maintenance

Plant Hierarchy

Petrochemical Plant



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Optimising Equipment Maintenance

Issues to consider

- Relationships between major units, equipment and components;
- Criticality;
- Access and windows of opportunity.

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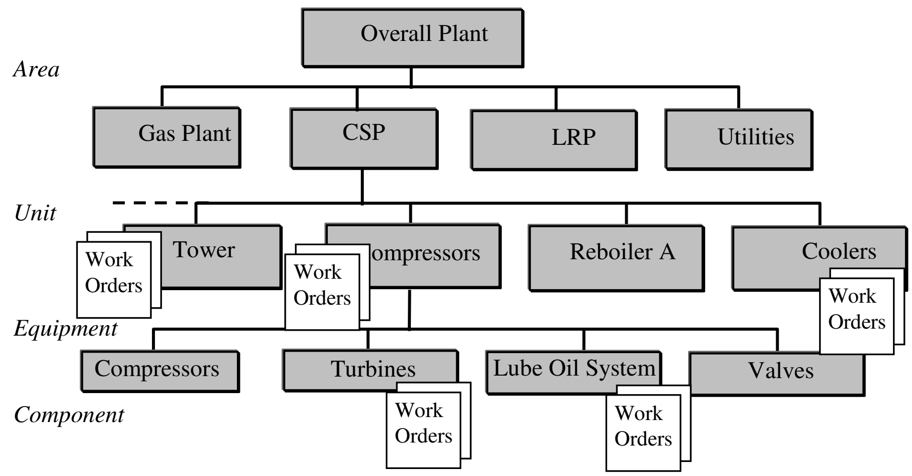
Optimising Equipment Maintenance

Plant Hierarchy

Petrochemical Plant



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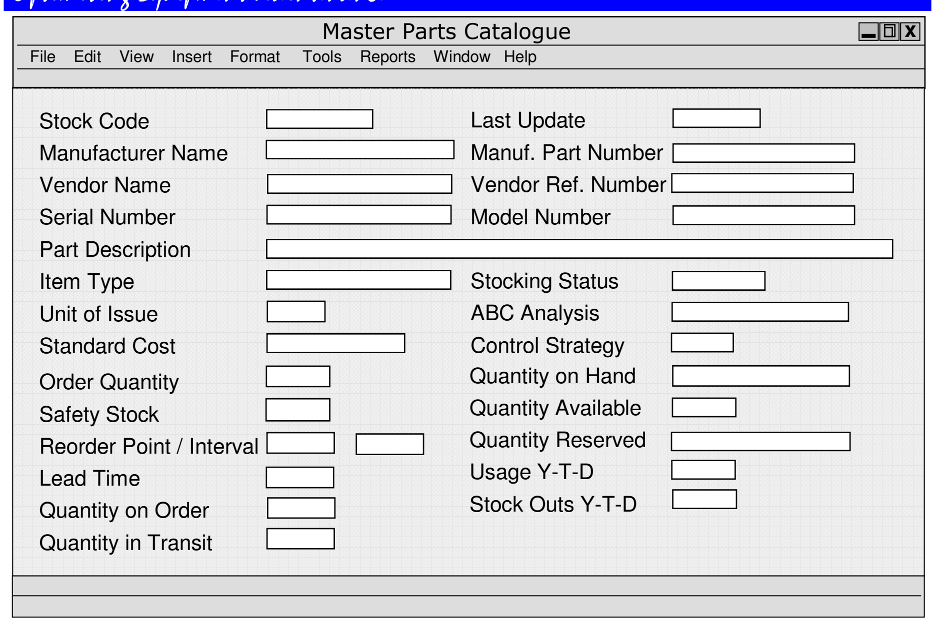
Optimising Equipment Maintenance



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Optimising Equipment Maintenance

Equipment History

File Edit View Insert Format Tools Reports Window Help

Work Order Number		Status / Date	
Work Order Type		Maintenance Type	
Priority		Work Request No.	
Work Order Description			
Equipment Description			
Equipment Id		Cost Code	
Manufacturer		Equipment Class	
Model Number		Serial Number	
Est. Company Labour		Act. Company Labour	
Est. Contract Labour		Act. Contract Labour	
Est. Materials		Act. Materials	
Est. Services		Act. Services	
Est. Other		Act. Other	
Est. Total		Act. Total	
Est/Actual Variance		Percentage Variance	

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Optimising Equipment Maintenance

Computerised Maintenance Management Systems

Best Practice Benchmarking Findings

Reference: Terrence O'Hanlon (CMRP) Reliabilityweb.com

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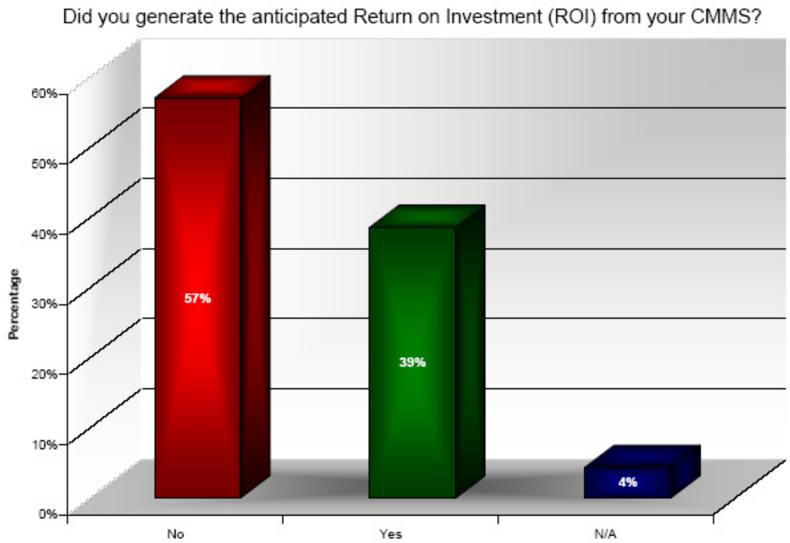
Optimising Equipment Maintenance



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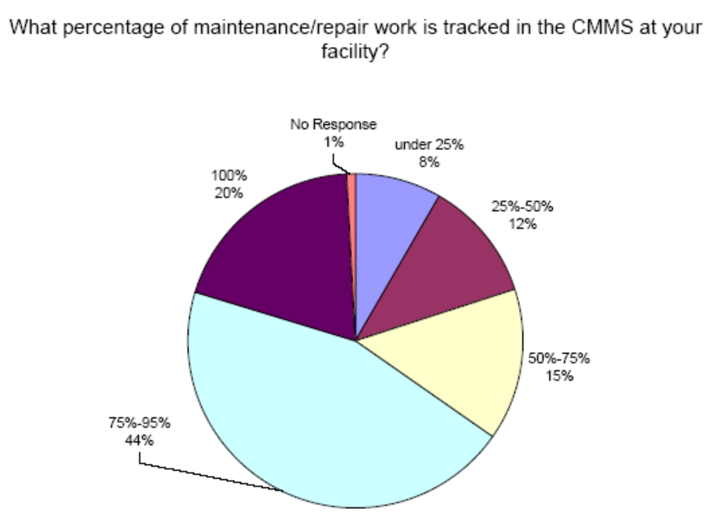

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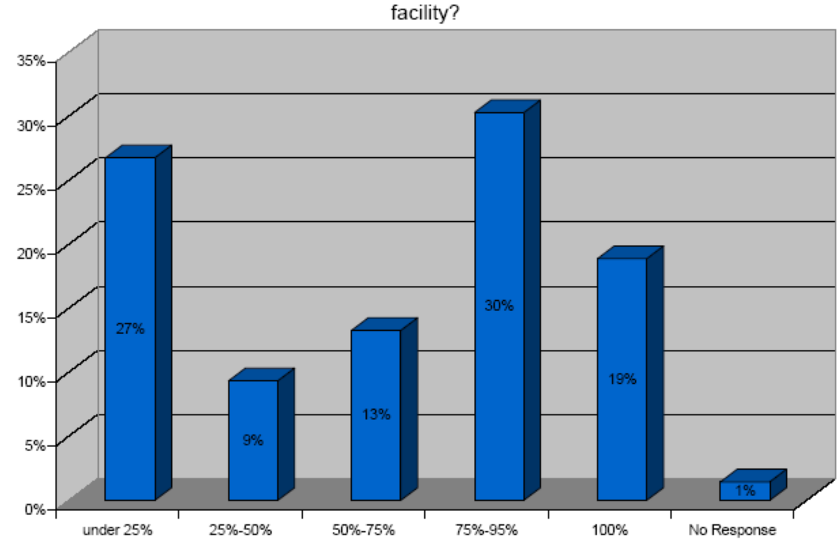
Optimising Equipment Maintenance

What percentage of maintenance spares inventory is tracked in the CMMS at your facility?



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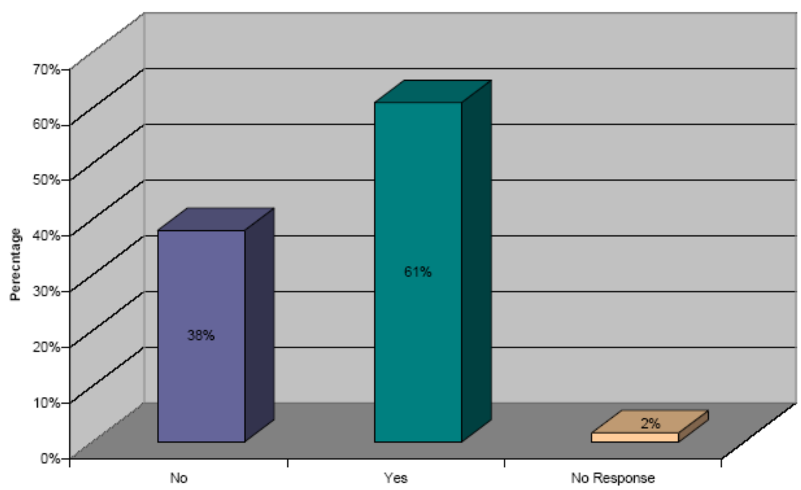
Optimising Equipment Maintenance

Did you make any changes to your maintenance work flow to accommodate your CMMS?



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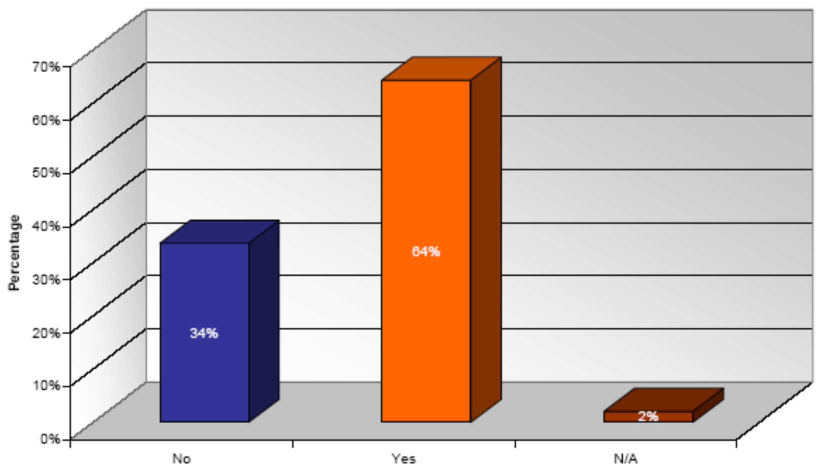
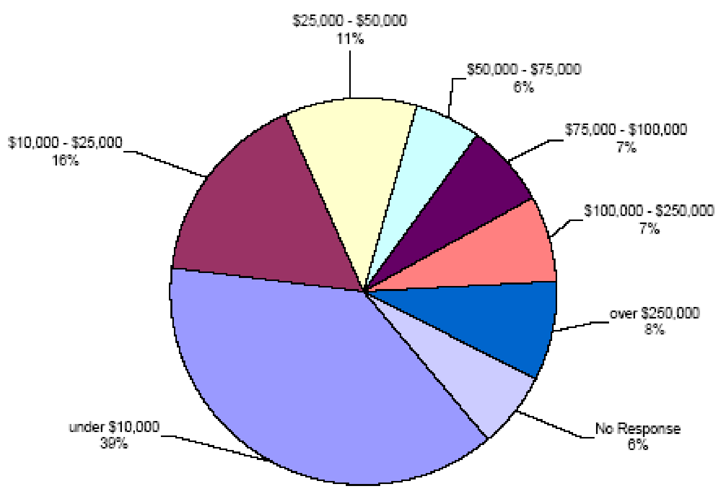
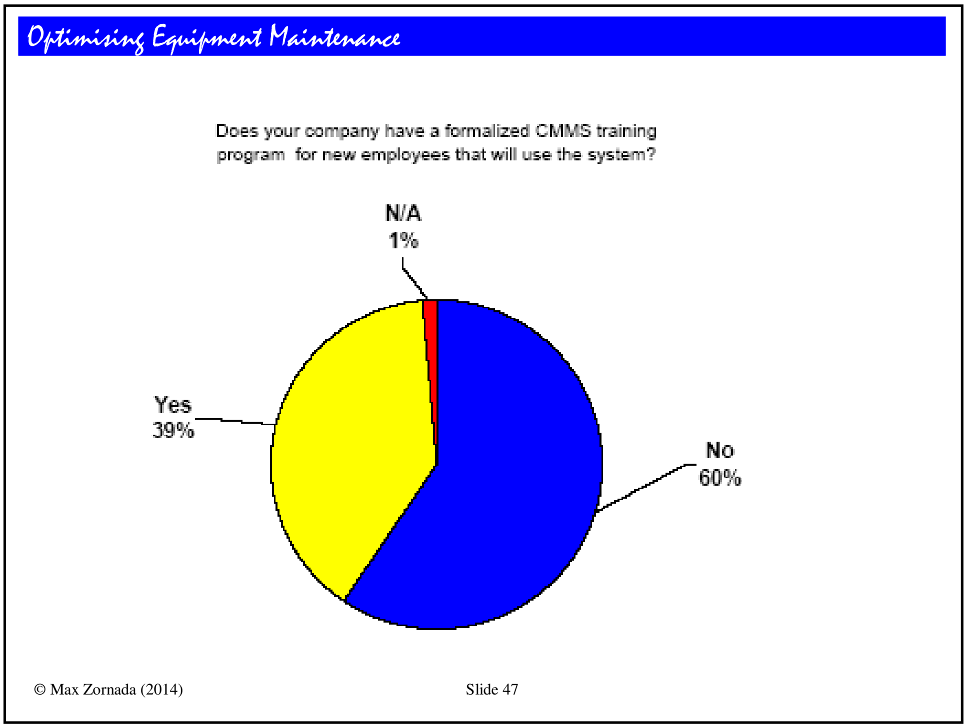
Did you customize your CMMS?



Optimising Equipment Maintenance

Please indicate how much is currently spent annually supporting your company CMMS with software upgrades, software maintenance and training.




Optimising Equipment Maintenance
Does your company have a formalized CMMS training program for new employees that will use the system?
N/A 1%
Yes 39%
No 60%
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