Reliability-Centered Maintenance - RCM

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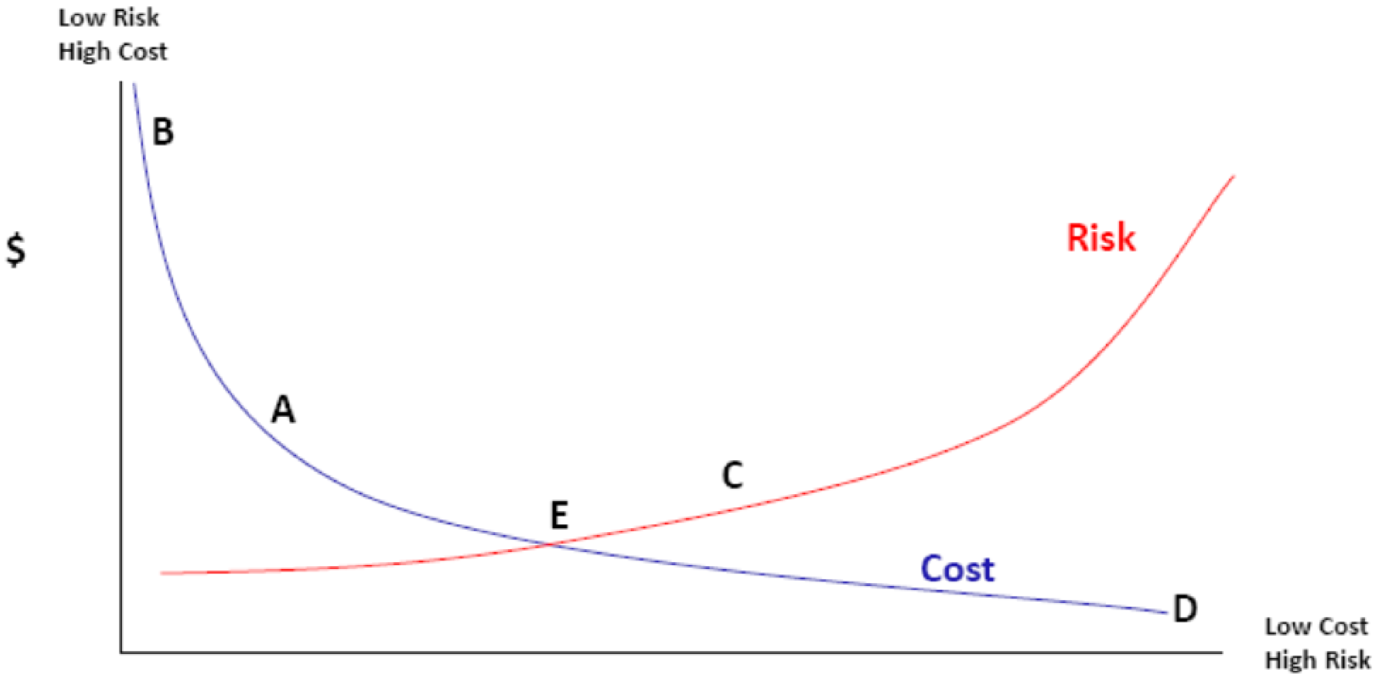
CHALMERS

LEARNING OBJECTIVE

After this lecture, the students should be able to:

LO1: Describe and apply risk and safety concepts and use engineering tools to analyze, evaluate, and reduce risks
LO2: Explain, implement and distinguish various prevailing maintenance concepts
LO6: Differentiate, select and develop actions to improve production systems or products during the whole life-cycle.


Low Risk
High Cost
$
B
A
E
C
Risk
Cost
D
Low Cost
High Risk

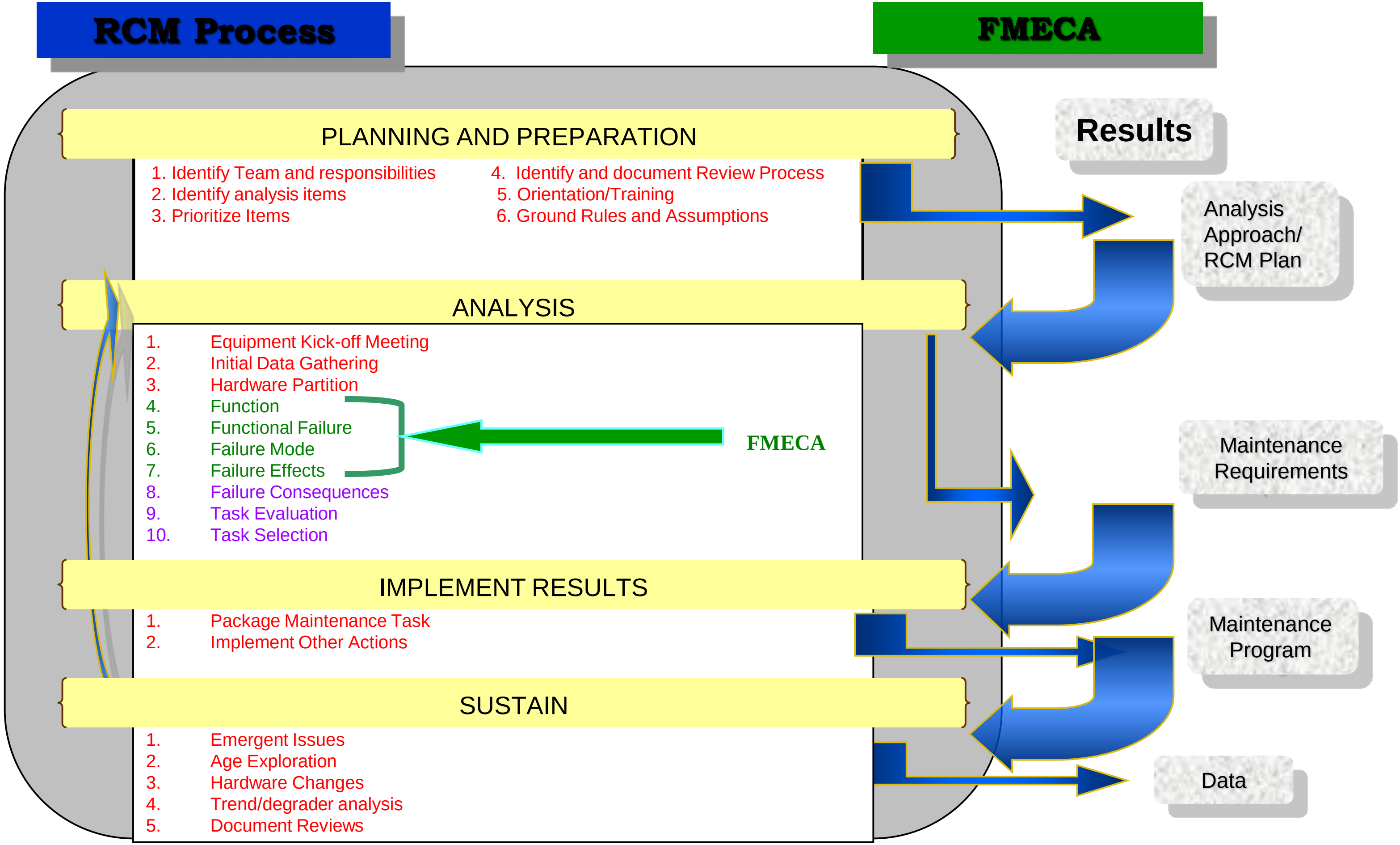
Risk management is the process of…

- Understanding
- Quantifying
- Prioritising
- Reviewing and constantly improving

The mitigation of risk to business operations

RCM PROCESS

1. ABC classification
   - Identification of critical machine(s)
2. Functional tree
   - Critical components
   - List of functions and its performance standards
3. Significant Function (SF) identification
4. FMECA
   - Critical/dominant Failure Modes (FM)
5. Take FM into RCM Decision Diagram for concequence analysis
   - Choose maintenance policies (PM, RTF, CM, Redesign)
6. Maintenance program
   - Package maintenance task


RCM Process
FMECA
Results
PLANNING AND PREPARATION
1. Identify Team and responsibilities
2. Identify analysis items
3. Prioritize Items
4. Identify and document Review Process
5. Orientation/Training
6. Ground Rules and Assumptions
Analysis Approach/ RCM Plan
ANALYSIS
1. Equipment Kick-off Meeting
2. Initial Data Gathering
3. Hardware Partition
4. Function
5. Functional Failure
6. Failure Mode
7. Failure Effects
8. Failure Consequences
9. Task Evaluation
10. Task Selection
FMECA
Maintenance Requirements
IMPLEMENT RESULTS
1. Package Maintenance Task
2. Implement Other Actions
Maintenance Program
SUSTAIN
1. Emergent Issues
2. Age Exploration
3. Hardware Changes
4. Trend/degrader analysis
5. Document Reviews
Data

The following describe the levels at which RCM can be applied:

- Part (or piece part): the lowest level to which equipment can be disassembled without damage to or destruction of the item involved
- Component (or black box): a grouping or collections of piece parts into some identifiable package that will perform at least one significant function as a stand-alone item. Modules, circuit boards, and subassemblies are often defined as intermediate buildup levels between parts and components
- System: a logical grouping of components that will perform a series of key functions required by a plant or facility
- Plant (or facility): logical grouping of systems that function together to provide an output (e.g., electricity) or product (e.g., ore, mineral) by processing and manipulating various input raw materials and feedstock (e.g., water, crude oil, natural gas, iron ore)

Reliability-Centered Maintenance (RCM)

RCM II: 7 basic questions: (Moubray, 1991)

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

Reliability Centered Maintenance (RCM) for Automated Mining Machinery

Seyed Hadi Hoseinie, Uday Kumar
Project leader: Behzad Ghodrati

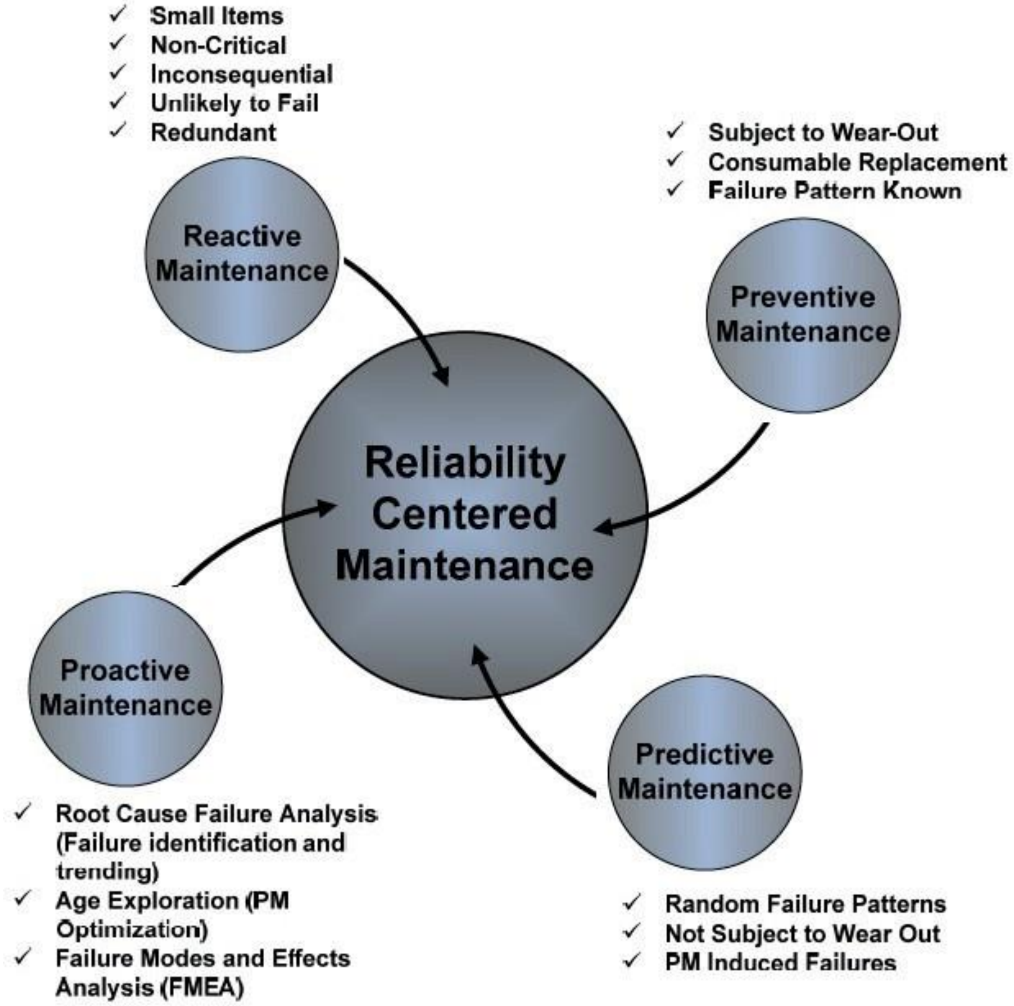
March 2016

Luleå University of Technology
Division of Operation and Maintenance Engineering

Step 6: Maintenance task selection

PM task selection in the last step of classic RCM; it provides the maintenance solutions based on the preceding five steps. The RCM process requires each task to pass the applicable and effective test, defined as follows:

- Applicable: the task will prevent or mitigate failure, detect onset of failure, or discover a hidden failure
- Effective: the task is the most cost-effective option among competing candidates


✓ Small Items
✓ Non-Critical
✓ Inconsequential
✓ Unlikely to Fail
✓ Redundant
Reactive Maintenance
✓ Subject to Wear-Out
✓ Consumable Replacement
✓ Failure Pattern Known
Preventive Maintenance
Reliability Centered Maintenance
Proactive Maintenance
✓ Root Cause Failure Analysis (Failure identification and trending)
✓ Age Exploration (PM Optimization)
✓ Failure Modes and Effects Analysis (FMEA)
Predictive Maintenance
✓ Random Failure Patterns
✓ Not Subject to Wear Out
✓ PM Induced Failures

How to select systems for RCM analysis

- Systems with a large number of corrective maintenance tasks during recent years;
- Systems with a large number of preventive maintenance tasks and/or costs during recent years;
- Systems with a high cost of corrective maintenance tasks during recent years;
- Systems contributing significantly towards plant outages/shutdowns (full or partial) during recent years;
- Systems causing high safety concerns; and
- Systems causing high environmental concerns.

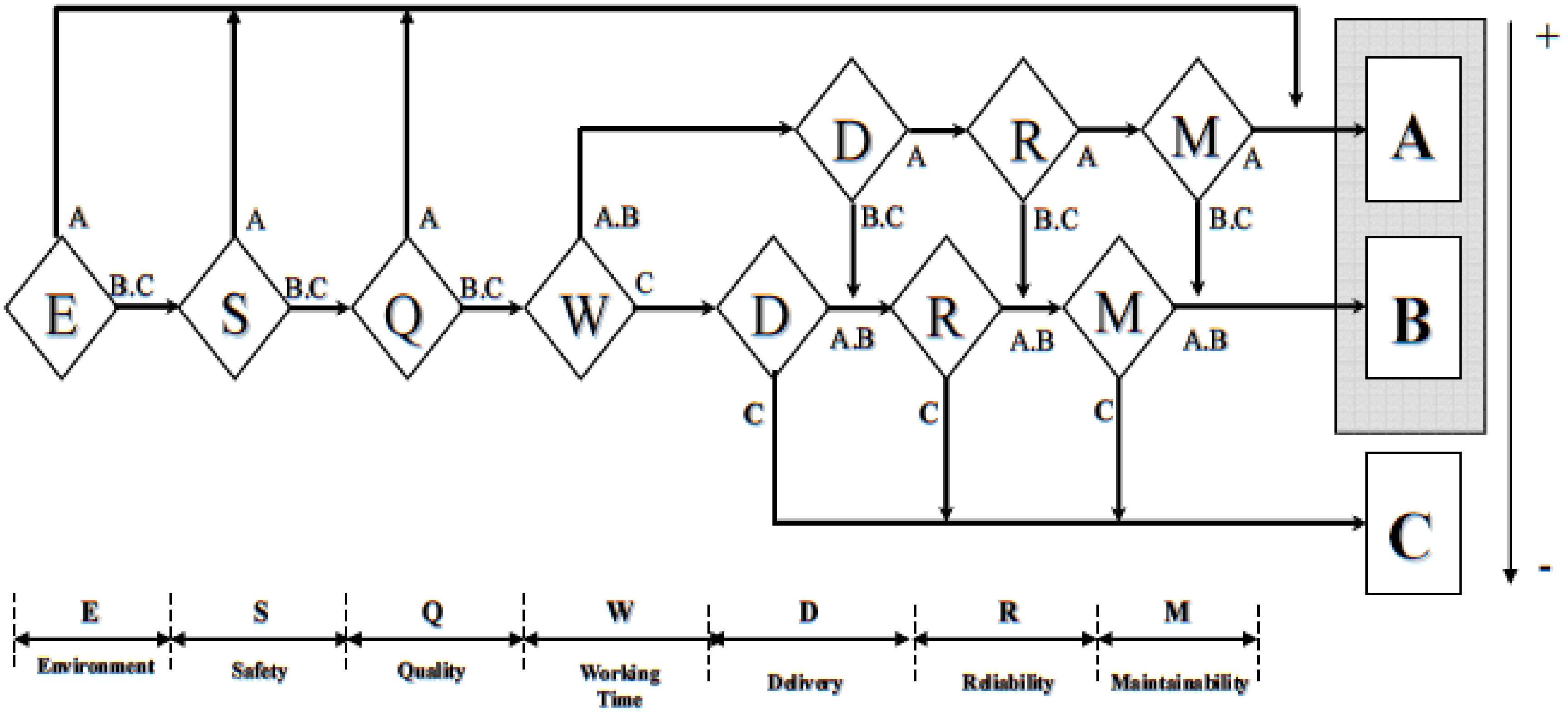


Figure 9.1. Flowchart criticality

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Identifying Functions:

FMECA

- **Consider all functions of an item**
- **Describe functions in terms of specific limits when possible**
- **State functions in terms of what the item is needed for**
- **Do not combine functions**
- **Function descriptions should include a verb, object, and applicable limits**

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Identifying Functions:

FMECA

All equipment has primary and secondary functions

FMECA for RCM analysis should identify ALL primary AND secondary functions. Typical Secondary Functions:

- **Control**
- **Warning or status indication**
- **Environmental protection**
- **Physical support or attachment**
- **Safety or protective functions**
- **Fluid Containment**
- **Comfort and Aesthetics**

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Identifying Functions:

FMECA

NAVAIR 00-25-403 RCM adds a categorization process to function identification called "significant function identification"

Intended to:

1) eliminate analysis of inconsequential functions
2) Ensure all significant functions are identified

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Identifying Functions:

FMECA

A SIGNIFICANT FUNCTION is one whose failure will have adverse effect on the end item with respect to:

- **Safety**
- **Environmental Health**
- **Operations**
- **Economics**

SIGNIFICANT FUNCTION (SF) IDENTFCATION

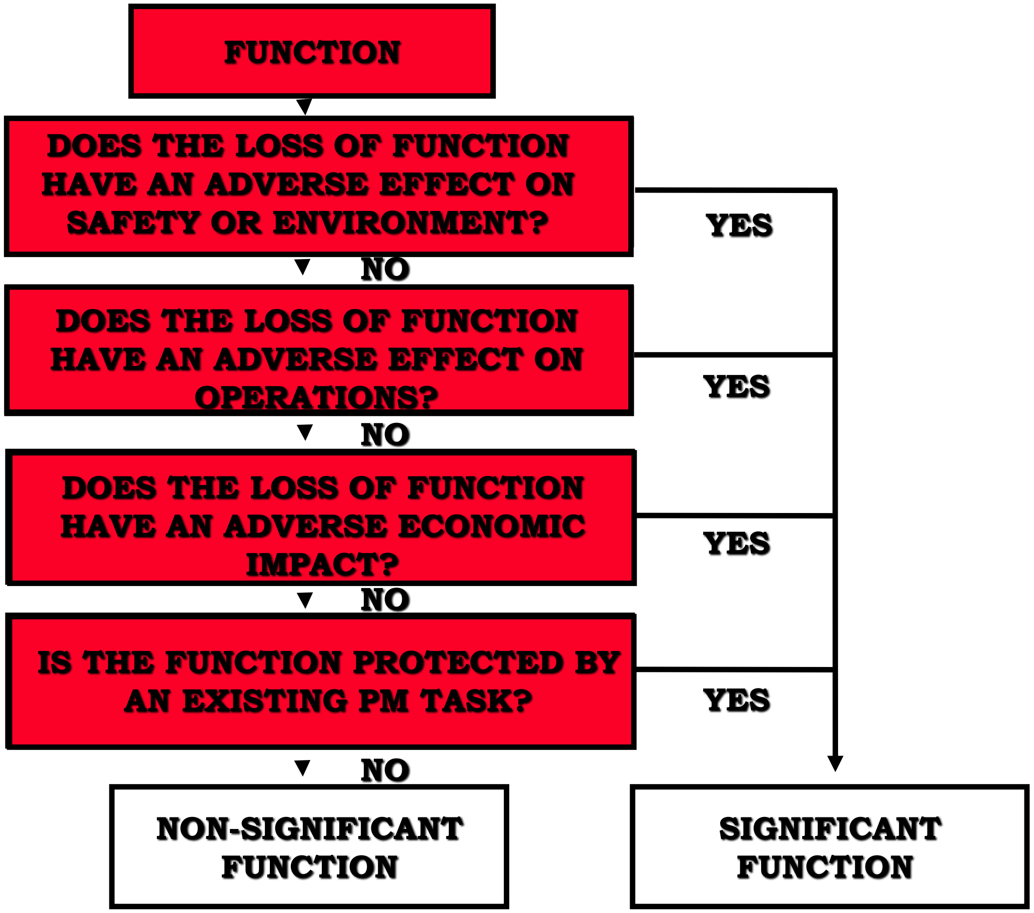


Figure 1. Steering gear system

Hidalgo et al. (2011), FMEA and FTA analysis applied to the steering system of LGN Carriers for the selection of maintenance policies

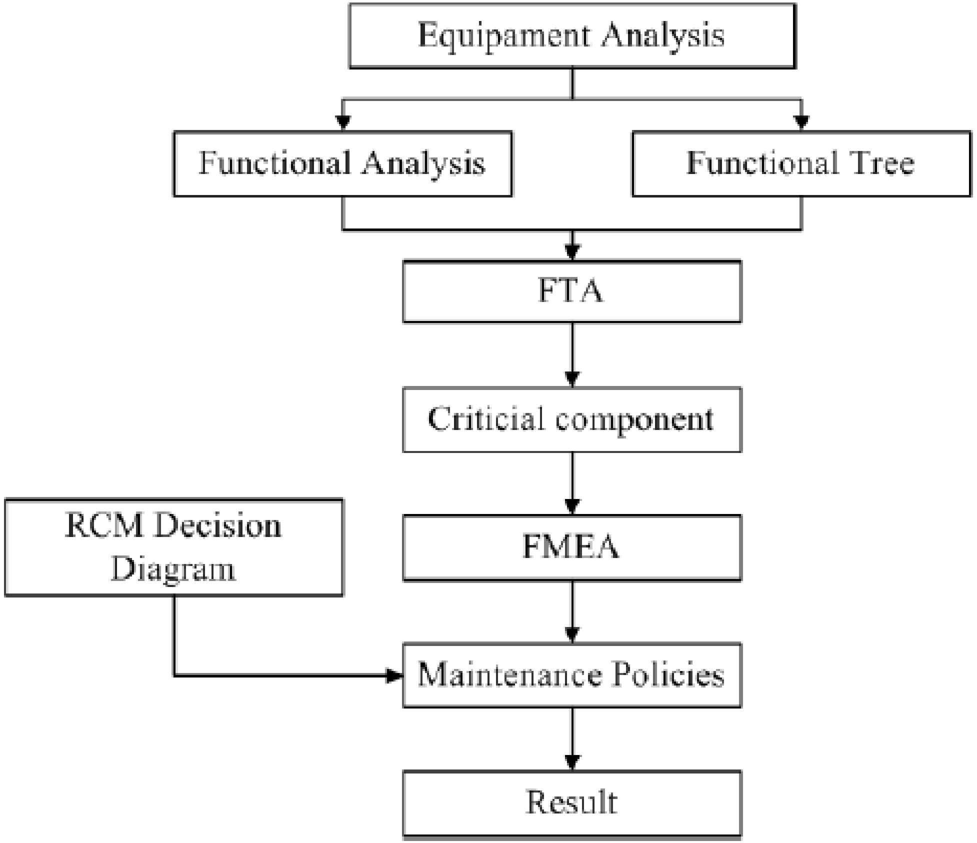


Figure 3. Flowchart representing the method main steps.

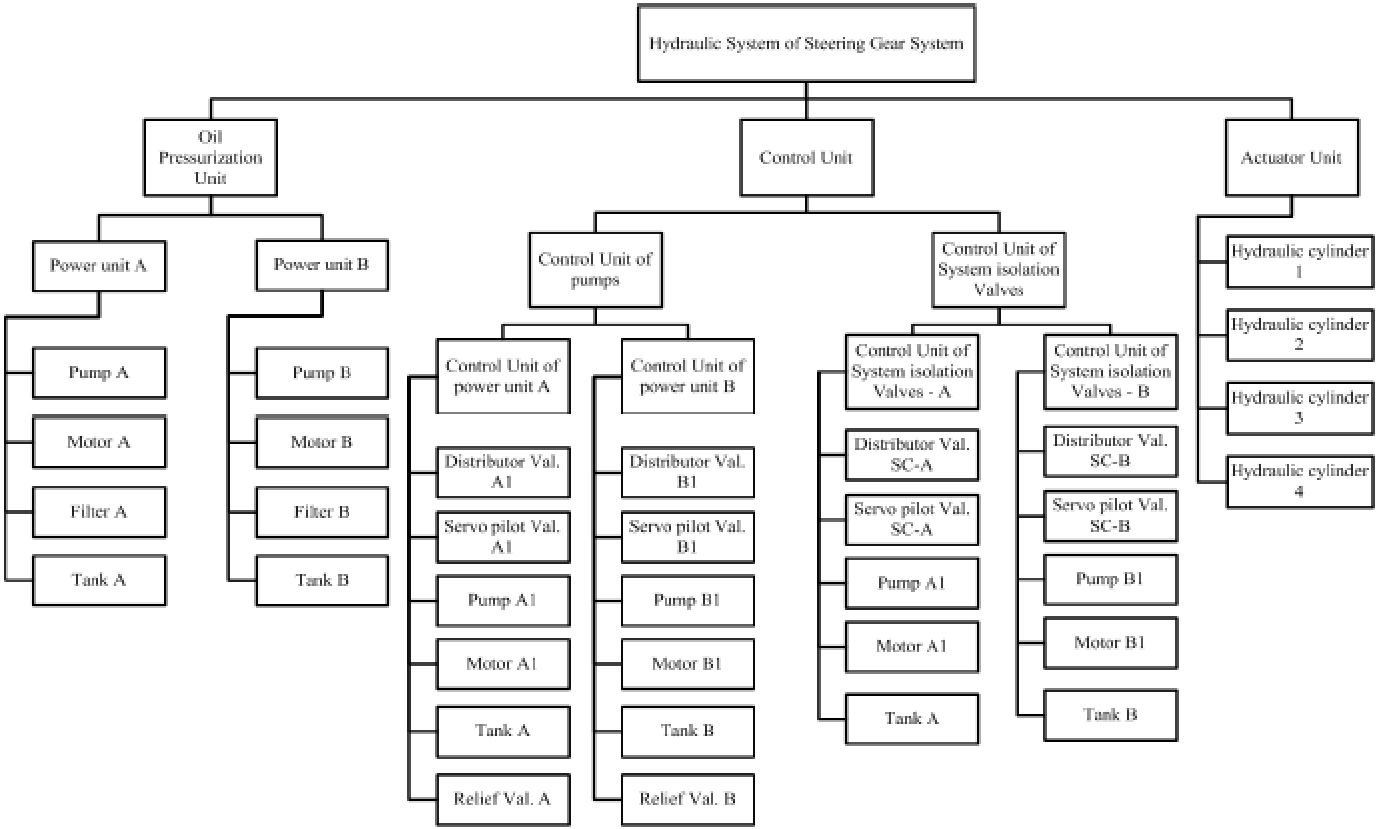


Figure 4. Funtional Tree of the hydraulic system in the steering gear system

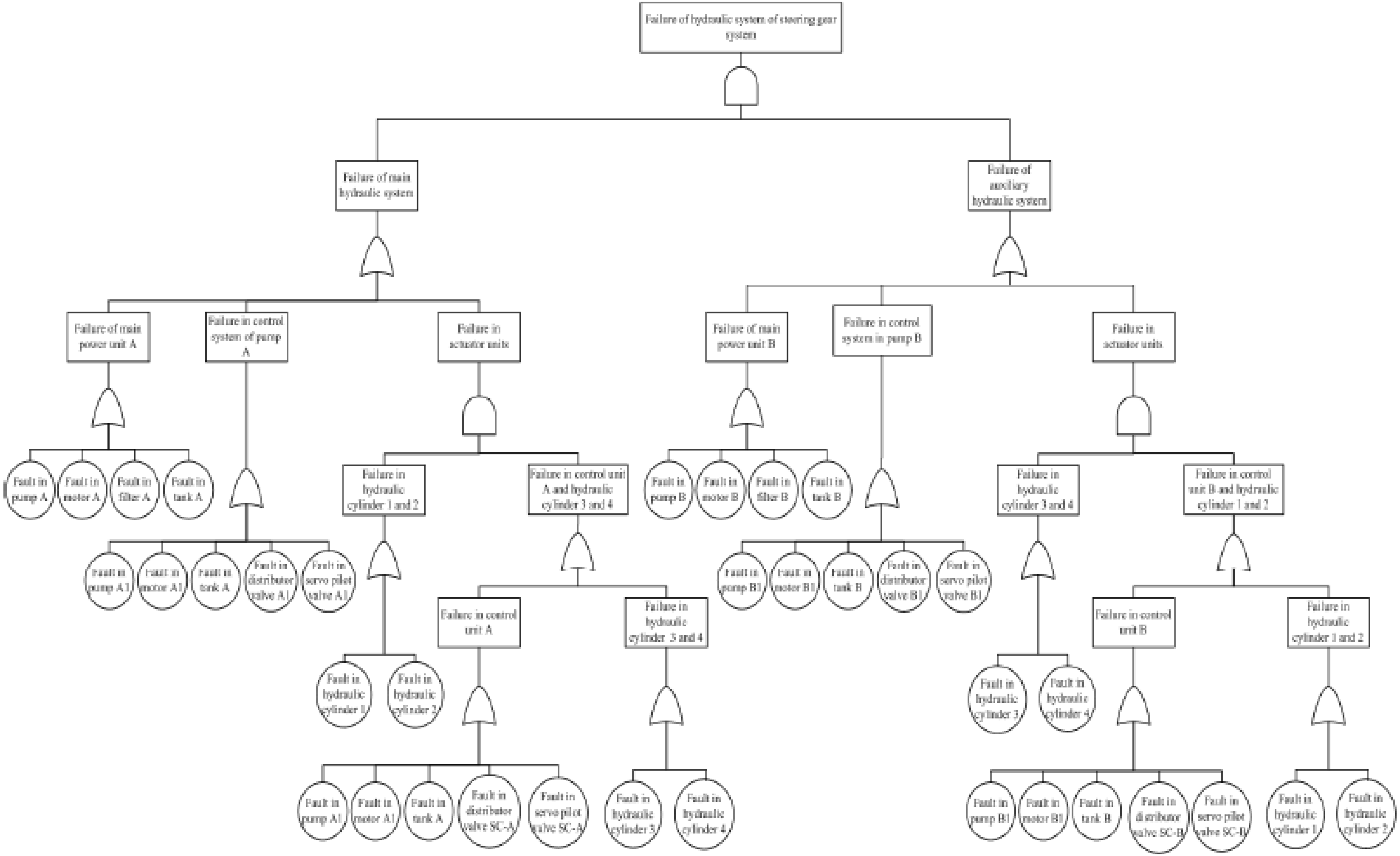


Figure 5. Fault Tree Analysis for hydraulic unit of the steering gear system operating in open water.

Table 2. The most critical components of the steering gear and their item importance.

Critical Components	Item importance
Pump A	0.4414
Pump B	0.4414
Servo Pilot Valve A1	0.1840
Servo Pilot Valve B1	0.1840
Distributor Valve A1	0.1815
Distributor Valve B1	0.1815
Pump A1	0.0775
Pump B1	0.0775
Motor A	0.0569
Motor B	0.0569

Table 3. Failure Modes and Effects Analysis of the variable delivery axial piston pump.

Component	Function	Failure Mode	Failure Causes	Failure Effects
Axial piston pump	Deliver the hydraulic fluid with a particular flow and constant pressure	Pump provides abnormal or unstable flow	Presence of air in the fluid	Absence or slow movement of the hydraulic cylinder (possible stop of steering gear system)
			Very high viscosity of the fluid	
			Cavitation	
			Excessive internal leakage	
			The suction strainer being too small or too dirty	
			Wrong installation of the pump	
		External leakage	Excessive pressure within the pump	Insufficient pressure in the hydraulic cylinders
			High temperature of the fluid	Incorrect speed of the cylinders hydraulic
			Wear on port plate and barrel faces	
			Wear on seal	

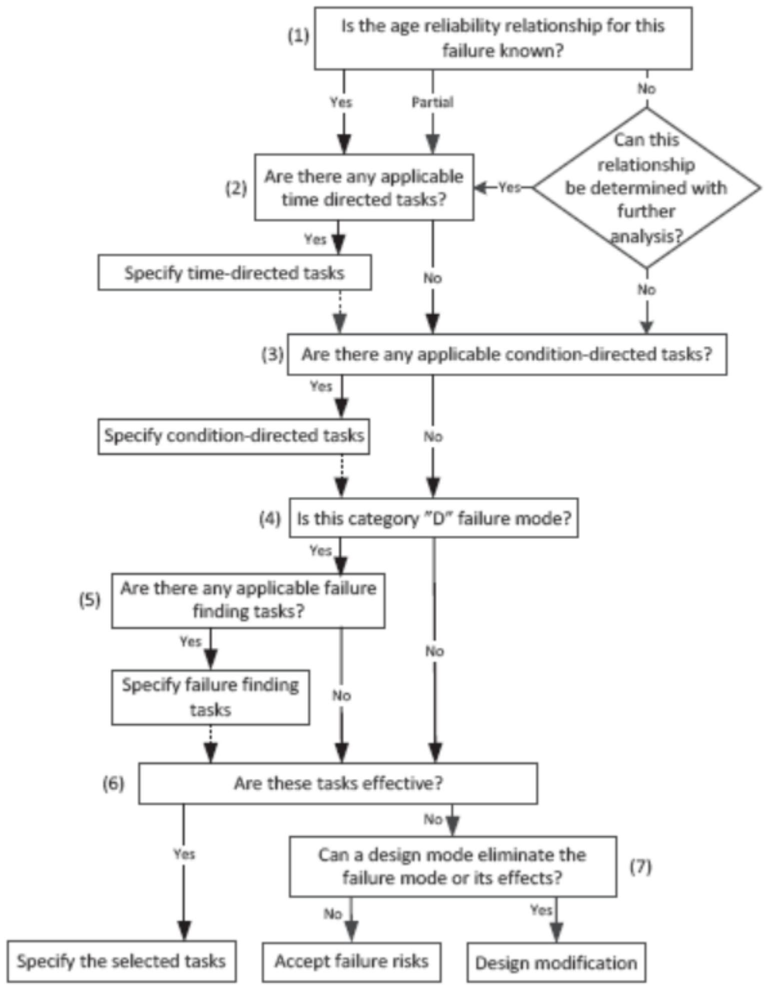


Figure 2.5. Task selection flowchart in RCM (adapted from [49])

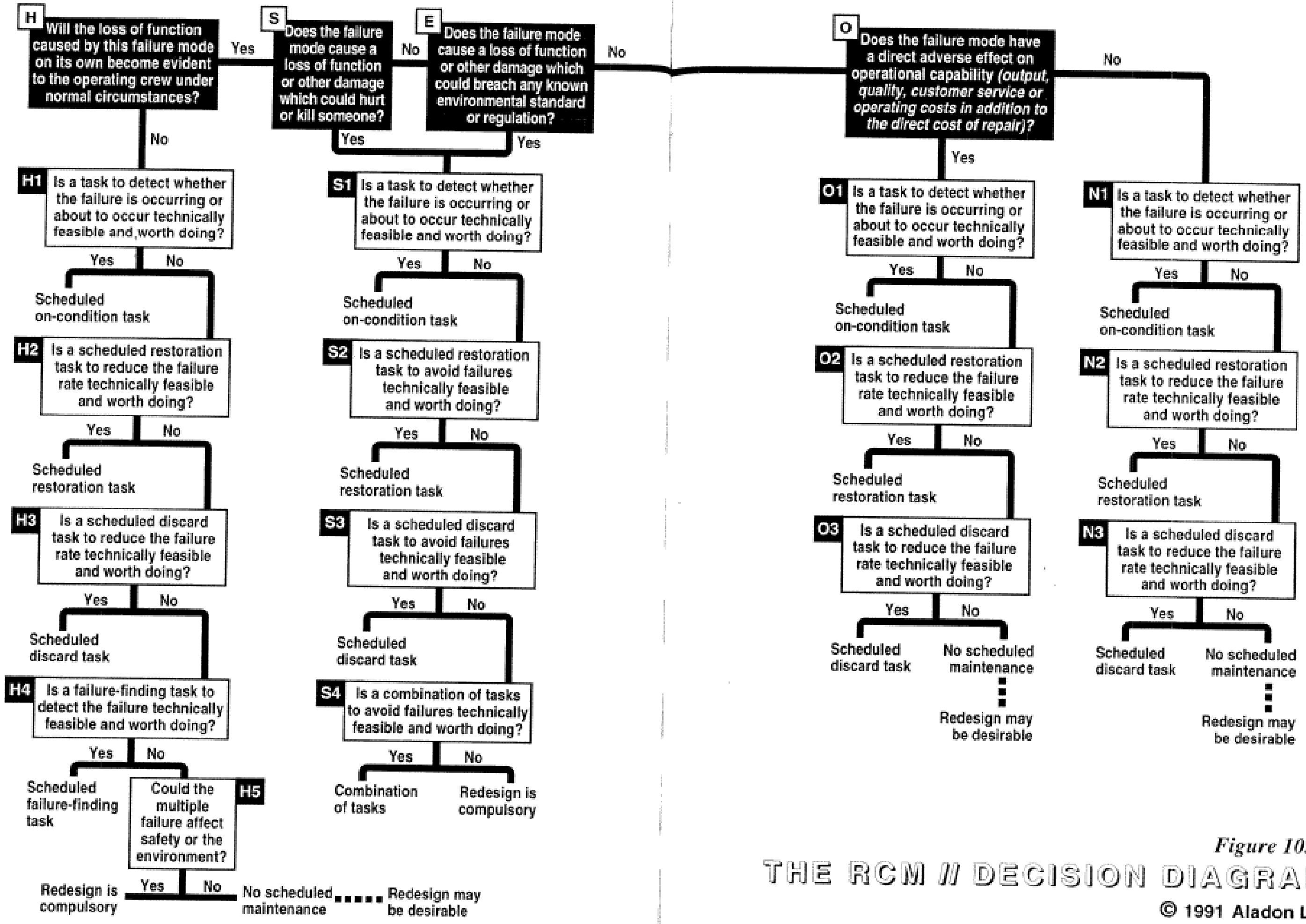


Figure 10.1:

THE RCM II DECISION DIAGRAM

Table 4. Maintenance policies for the variable delivery axial piston pump.

	System				Steering Gear						
	Sub-system				Variable delivery axial piston pump						
Failure Modes	Consequence evaluation				H1 S1 O1 N1	H2 S2 O1 N2	H3 S3 O3 N3	Default Action			Proposed Task
	H	S	E	O				H4	H5	S4	
Pump provides abnormal or unstable flow	N	S	S	S	x	x					**Preventive maintenance tasks**
											1. Clean the internal components (during the machinery overhaul)
											2. Clean the suction pipelines (during the machinery overhaul)
											Predictive maintenance tasks
											1. Vibration analysis (every month)
											2. Oil analysis (every 2 months)
											3. Ultrasonic test (every 3 months)
External leakage	N	S	S	S	x	x					**Preventive maintenance tasks**
											1. Periodic inspections (every day)
											2. Seal inspections (during the machinery overhaul)
											Predictive maintenance tasks
											1. Vibration analysis (every month)
											2. Monitoring the operational pressure (during the periodic inspection)

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Study of existing RELIABILITY CENTERED MAINTENANCE (RCM) APPROACHES USED IN DIFFERENT INDUSTRIES

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3.4 RCM IN CHEMICAL INDUSTRIES

Reliability Centred Maintenance (RCM) is being extensively used into this industrial area, existing strong regulations and development criteria. The **state of the art of its regulations and applications** is shown below.

A variety of safety laws and regulations dealing specifically with catastrophic chemical accidents have come about recently. Among the first attempts to deal with chemical disasters were those in Europe, following the Flixborough, U.K., vapour-cloud explosion in 1974 and the release of toxic materials in Seveso, Italy, two years later. The bulk of U.S. efforts for prevention of major chemical plant accidents began in the aftermath of the Bhopal tragedy in 1984. A more recent U.S. regulation that addresses accidental releases stems from the passing of the Clean Air Act Amendments (CAAA) in November 1990. This legislation mandates that EPA create regulations to require facilities possessing listed chemicals above a threshold amount to develop and to implement extensive risk-management plans (RMPs).

Due to tragedies, chemical companies must follow a well established set of laws and rules to enforce security and reliability. The methods approved by OSHA include, but are not limited to: What-If Analysis, Checklist Analysis, What-If/Checklist Analysis, Hazard and Operability (Hazop) Analysis, Failure Modes and Effects Analysis (FMEA), FTA, or Fault Tree Analysis. All of them are included into the RCM process used in chemical companies.

Occupational Safety and Health Administration (OSHA)

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Identifying Functions:

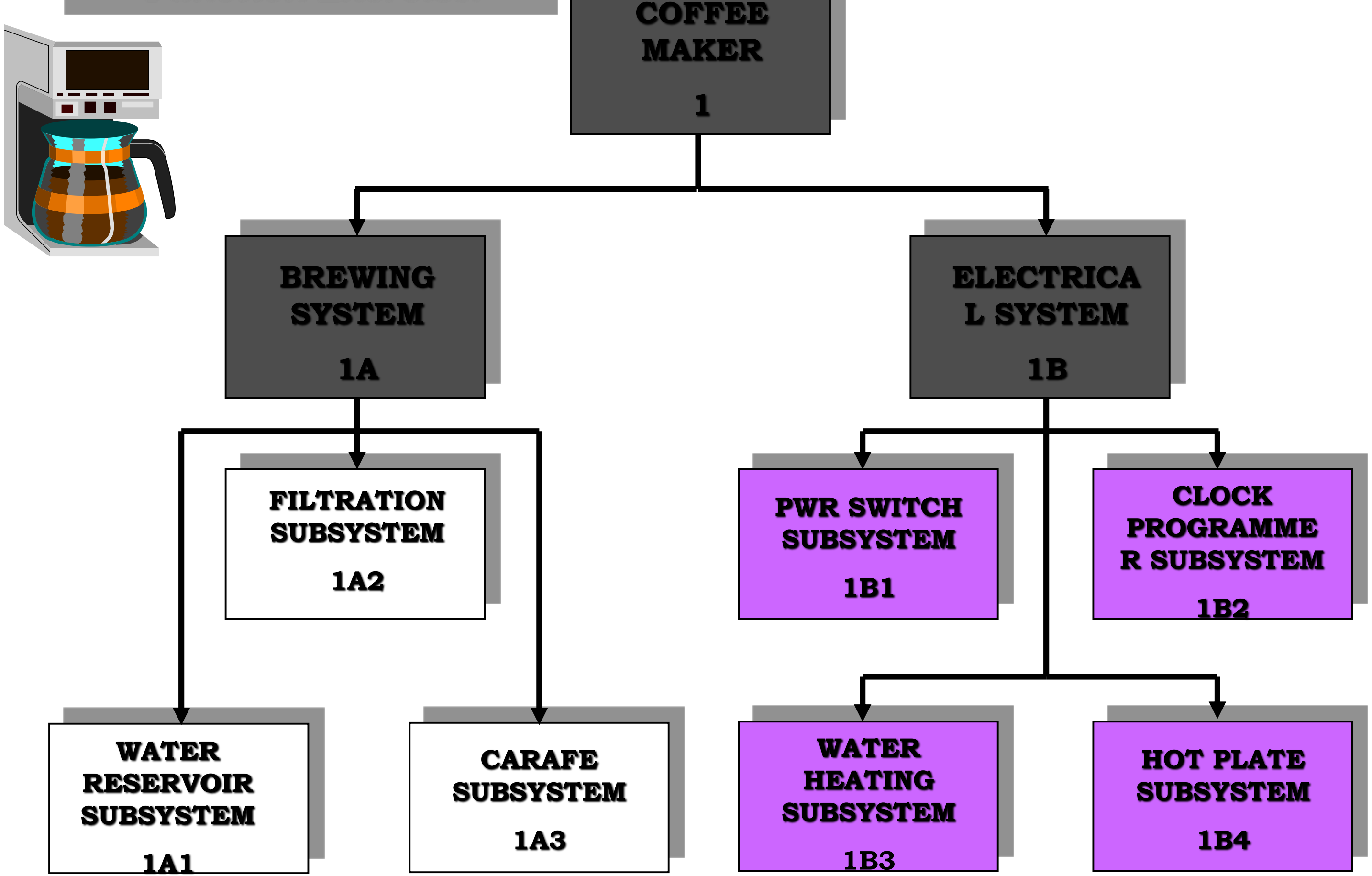
FMECA

Class Exercise

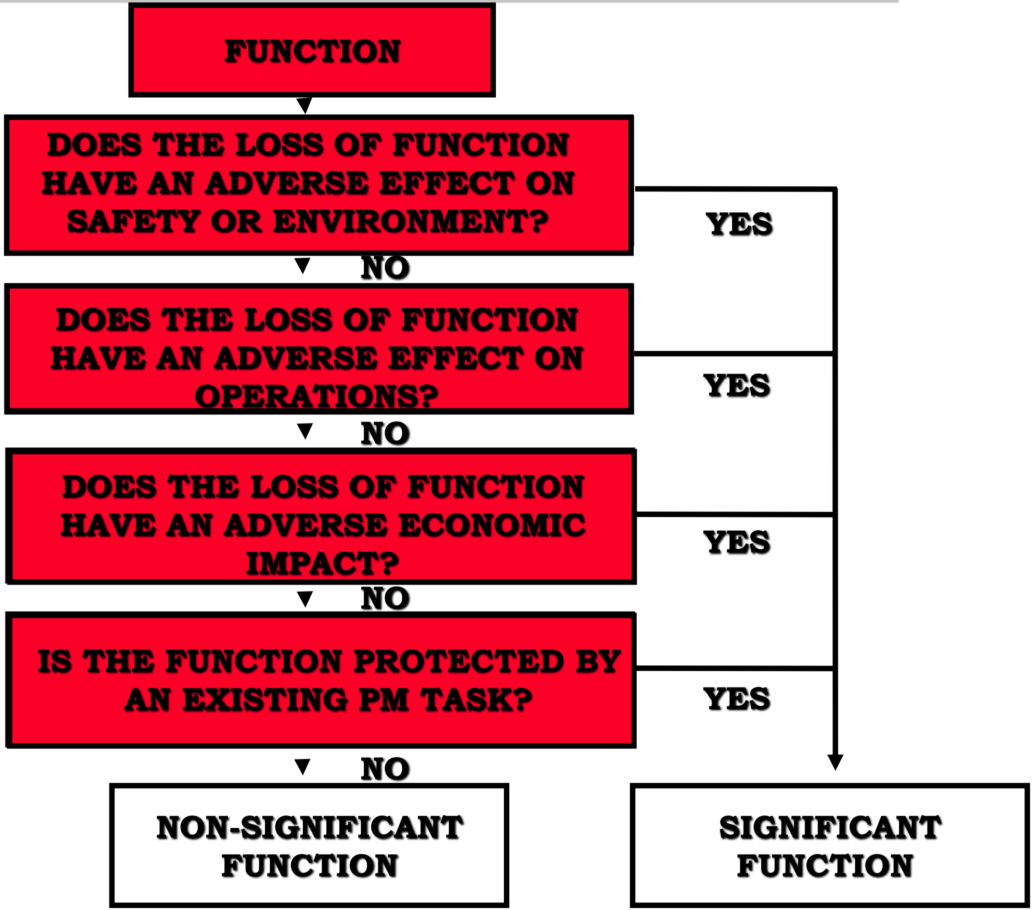
Objective:
List the functions of a Coffee Maker

Do a functional tree for the coffee maker!

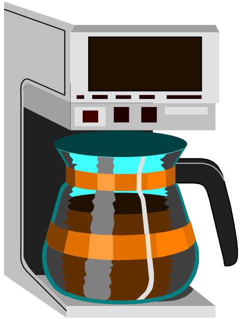
Function Exercise:



Now select the Significant Funktions – SF !

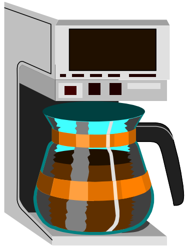


FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)



Coffee Maker Functions

1. Brew 1 to 12 cups of coffee
2. Maintain coffee at 120°f ± 5°f
3. Automatically start brewing process within 15 minutes of time specified by user
4. Automatically shut down coffee maker 4 hours after brew cycle is completed
5. Contain coffee in carafe
6. Contain 1 carafe of water in reservoir
7. Provides safe handling of hot coffee



FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Identifying FMECA Terms:

FMECA

Class Exercise

Objective:

Identify and list the coffee maker's Functional Failures

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Coffee Maker
Functional Failures

FUNCTION 1 – Brew 1 to 12 cups of coffee

FUNCTIONAL FAILURE A - Fails to brew coffee

FUNCTION 2 - Maintain coffee temperature at 120°f ± 5° f

FUNCTIONAL FAILURE A – Doesn't keep coffee warm(< 100°f)

FUNCTIONAL FAILURE B – Heats Coffee too hot (>125° f)

FUNCTIONAL FAILURE C – Partial warm coffee (>100°f but < than 115°f)

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Identifying FMECA Terms:

FMECA

Class Exercise

Objective:

Identify and list the Coffee Maker's

- **Failure Modes**
- **Failure Effects**

Extra Credit

- **Describe how operating context impacts failure effects (Residential vs Commercial Use)**

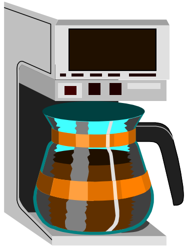
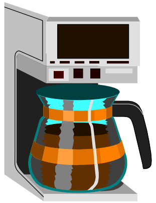


Table 2.3. Typical descriptors for failure modes [49]

abrasion		damaged		lack of ….		ruptured	
arcing		defective		leak		scored	
backward		delaminated		loose		scratched	
out of balance		deteriorated		lost		separated	
bent		disconnected		melted		shattered	
binding		dirty		missing		sheared	
blown		disintegrated		nicked		shorted	
broken		ductile		notched		split	
buckled		embrittlement		open		sticking	
burned		eroded		overheat		torn	
chafed		exploded		Over-temp		twisted	
chipped		false indication		overload		unbounded	
clogged		fatigue		overstress		unstable	
collapsed		fluctuates		overpressure		wrapped	
cut		frayed		over-speed		worn	
contaminated		intermittent		pitted			
corroded		incorrect		plugged			
cracked		jammed		punctured			

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Coffee Maker
Failure Modes and Effects



FUNCTION 1- Brew 1 to 12 cups of coffee

FUNCTIONAL FAILURE A – Fails to brew coffee

FAILURE MODE 1 - Clogged heating chamber tubing due to excessive calcium build-up.

FAILURE EFFECT - No coffee

FAILURE MODE 2 - Shorted wiring due to frayed insulation.

FAILURE EFFECT - Possible fire

FAILURE MODE 3 - Open On/Off switch due to corrosion.

FAILURE EFFECT - No coffee

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Coffee Maker
Failure Modes and Effects

FUNCTION 2 - Maintain coffee temperature at 120°f ± 5°f.

FUNCTIONAL FAILURE A - Fails to heat coffee (< 100°f)

FAILURE MODE 1 – Broken power supply wire to heating element connection.

FAILURE EFFECT - Cold coffee

FAILURE MODE 2 – Heating plate thermostat internal failure.

FAILURE EFFECT - Cold coffee

FUNCTIONAL FAILURE B - Heats coffee to hot (>125° f)

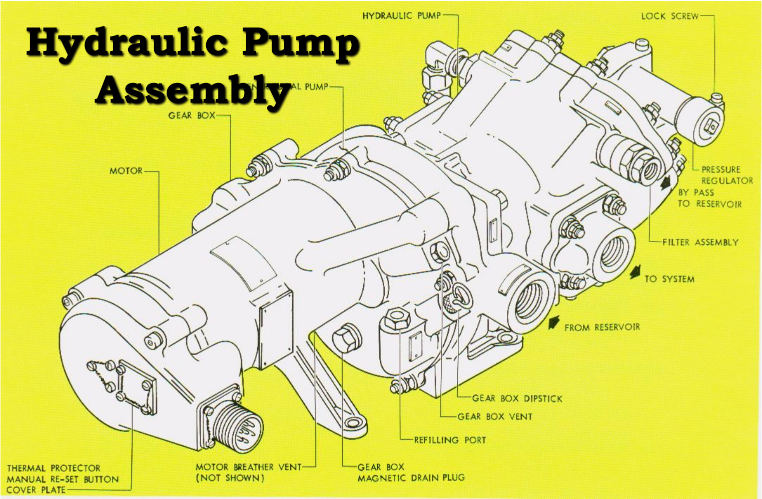
FAILURE MODE 1 – Corroded heating plate thermostat.

FAILURE EFFECT - Possible damage to coffee maker. Possible fire.

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

FMECA Terms:

FMECA



Fails to provide hydraulic fluid at a pressure of 3000 psi +/- 200 psi

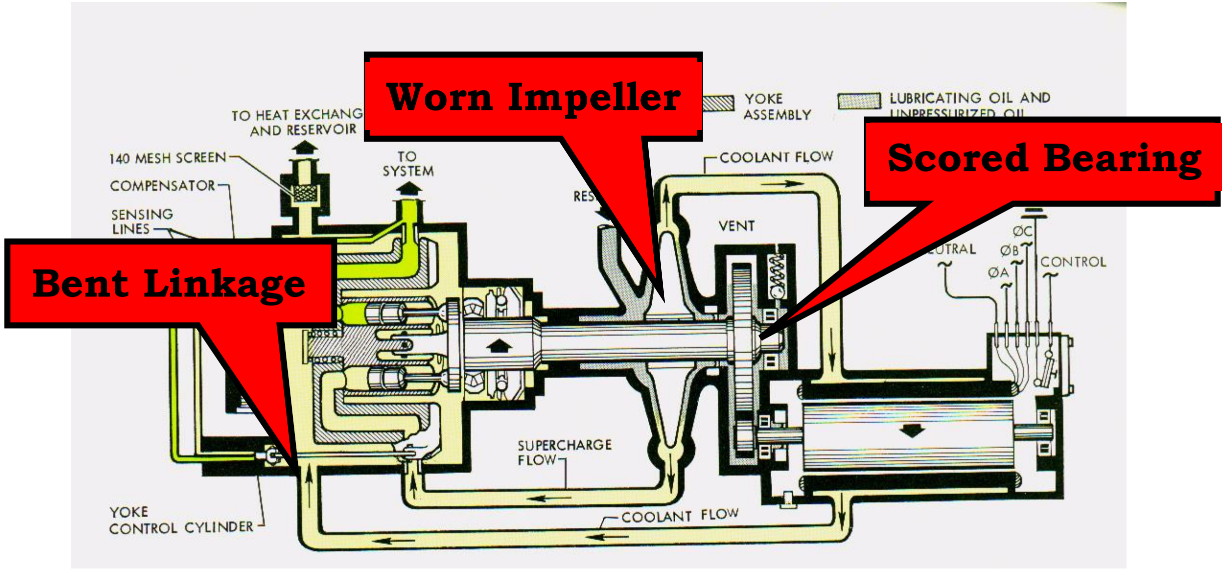
FUNCTIONAL FAILURE

The inability of an item to perform a specific function within specified limits.

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

FMECA Terms:

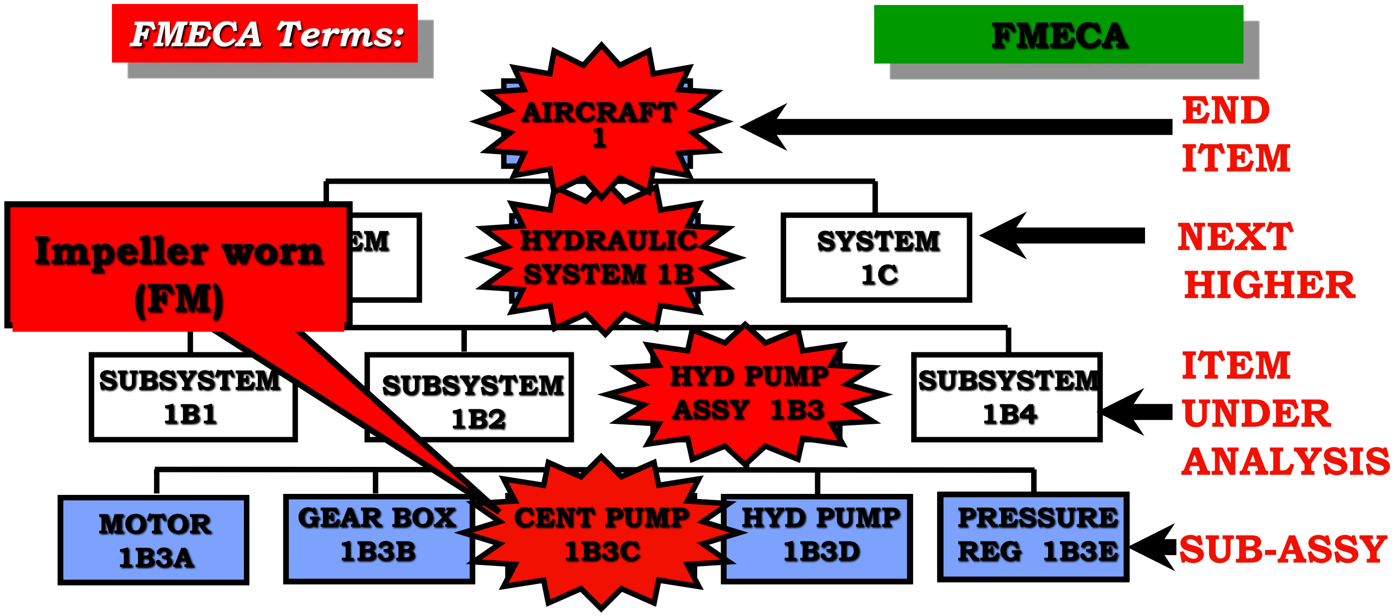
FMECA



FAILURE MODE

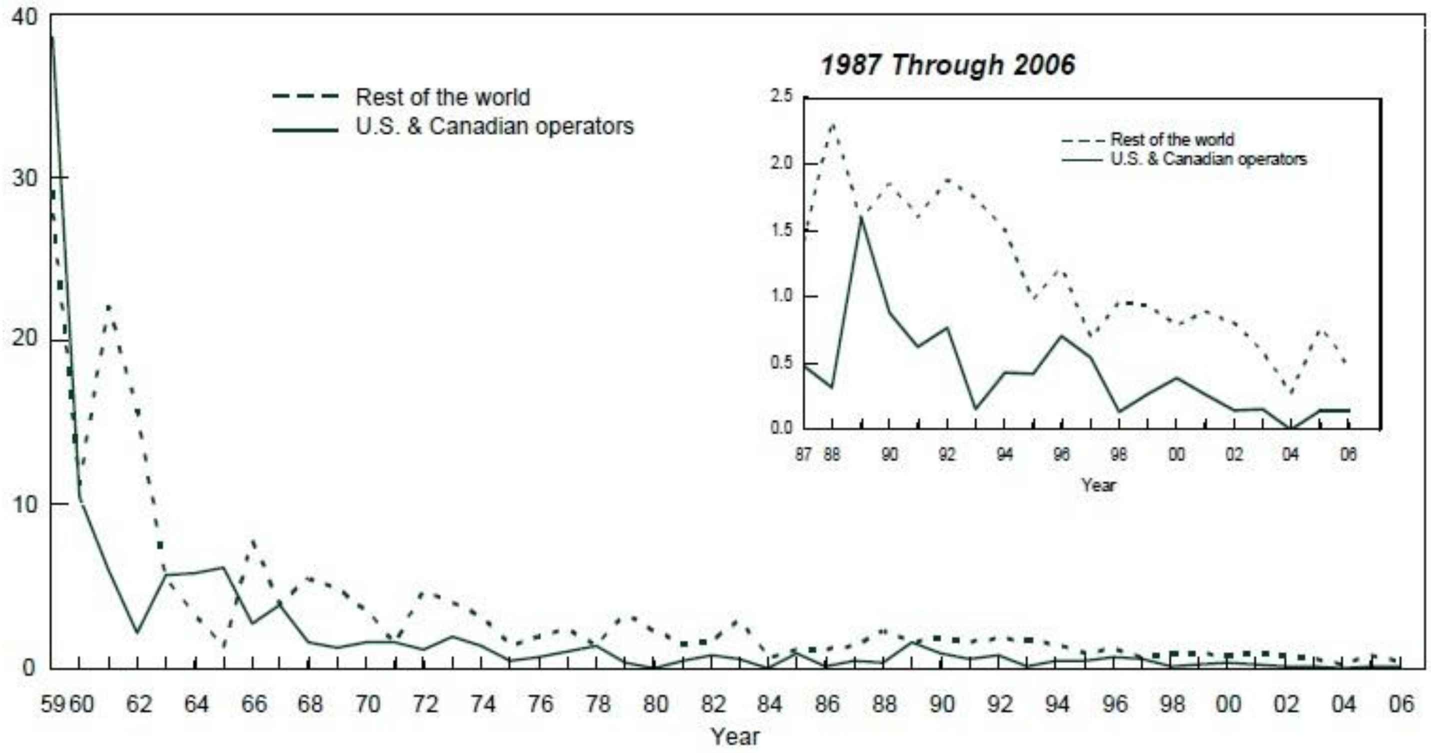
A specific physical condition that causes a particular functional failure.

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)



FAILURE EFFECT

The result of a failure mode and it's functional failure on surrounding items, the functional capability of the end item, and hazards to personnel and environment.


1987 Through 2006
Rest of the world
U.S. & Canadian operators
Year

- There was one fatal accident per five million departures in the United States in 2008
- Equipment failure accounts for 1/30 (compared to 2/3 in 1958)
- Eight million people travel every day
- There are 50 000 flights per day (passenger aircraft)

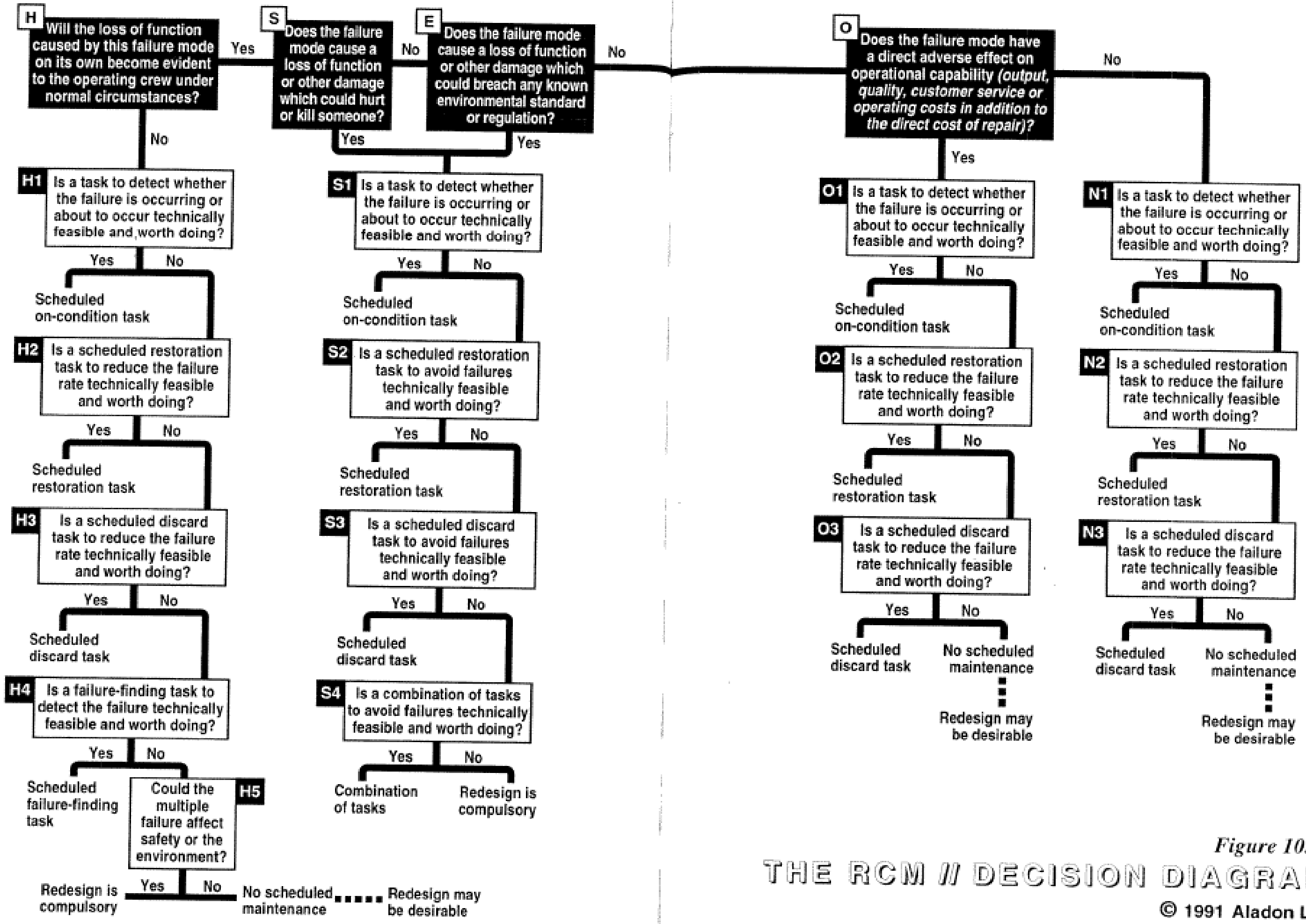


Figure 10.1:

THE RCM II DECISION DIAGRAM

Table 4. Maintenance policies for the variable delivery axial piston pump.

<table>
<tr><td colspan="2"></td><td colspan="3">System</td><td colspan="7">Steering Gear</td></tr>
<tr><td colspan="2"></td><td colspan="3">Sub-system</td><td colspan="7">Variable delivery axial piston pump</td></tr>
<tr><td rowspan="2">Failure Modes</td><td colspan="4">Consequence evaluation</td><td>H1
S1</td><td>H2
S2</td><td>H3
S3</td><td colspan="3">Default Action</td><td rowspan="2">Proposed Task</td></tr>
<tr><td>H</td><td>S</td><td>E</td><td>O</td><td>O1
N1</td><td>O1
N2</td><td>O3
N3</td><td>H4</td><td>H5</td><td>S4</td></tr>
<tr><td rowspan="7">Pump provides abnormal or unstable flow</td><td rowspan="7">N</td><td rowspan="7">S</td><td rowspan="7">S</td><td rowspan="7">S</td><td rowspan="7">x</td><td rowspan="7">x</td><td rowspan="7"></td><td rowspan="7"></td><td rowspan="7"></td><td rowspan="7"></td><td>Preventive maintenance tasks</td></tr>
<tr><td>1. Clean the internal components (during the machinery overhaul)</td></tr>
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<tr><td>3. Ultrasonic test (every 3 months)</td></tr>
<tr><td rowspan="6">External leakage</td><td rowspan="6">N</td><td rowspan="6">S</td><td rowspan="6">S</td><td rowspan="6">S</td><td rowspan="6">x</td><td rowspan="6">x</td><td rowspan="6"></td><td rowspan="6"></td><td rowspan="6"></td><td rowspan="6"></td><td>Preventive maintenance tasks</td></tr>
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<tr><td>2. Monitoring the operational pressure (during the periodic inspection)</td></tr>
</table>

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Guidance:

References

- NAVAIR 00-25-403: Guidelines for the Naval Aviation RCM process
- SAE JA1012: Society of Automotive Engineers Guide to RCM Standard
- RAC-HDBK-1120: FMECA - Failure Mode, Effects and Criticality Analysis
- MIL-STD-1629A: Procedures for Performing a Failure Mode, Effects, and Criticality Analysis
- MIL-HDBK-217: Reliability Prediction of Electronic Equipment.
- MIL-STD-882D: Standard Practice For System Safety
- NAVAIRINST 5100.11: Research and Engineering Review of Risk Process and Procedures for Processing Grounding Bulletins

FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

Sources:

References

Useful Data Sources For Identifying FMECA Information are:

- Maintenance/Operators Manuals
- Troubleshooting Guides/Charts
- Drawings
- Operators/Maintainers/Engineers/OEM Tech Reps
- Work Orders/CMMS or other failure data
- Block Diagrams/Schematics
- Existing PM Tasks
- Accident/Incident/Hazard reports
- Engineering/Failure Investigations/Test reports

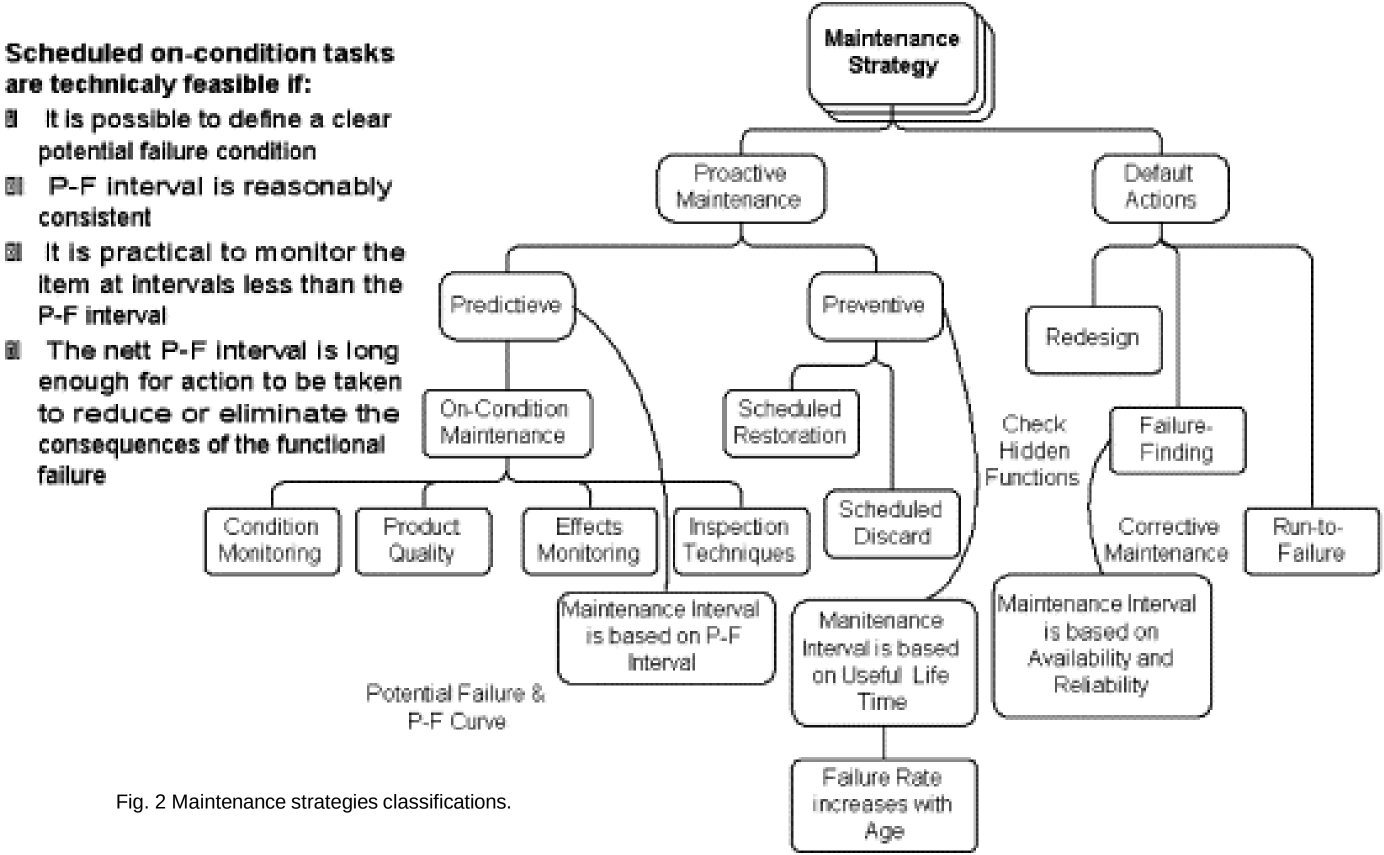


Fig. 2 Maintenance strategies classifications.

Computer-aided RCM-based plant maintenance management system

Robotics and Computer-Integrated Manufacturing, Volume 19, Issue 5, 2003, 449 - 458

Hossam A Gabbar , Hiroyuki Yamashita , Kazuhiko Suzuki , Yukiyasu Shimada

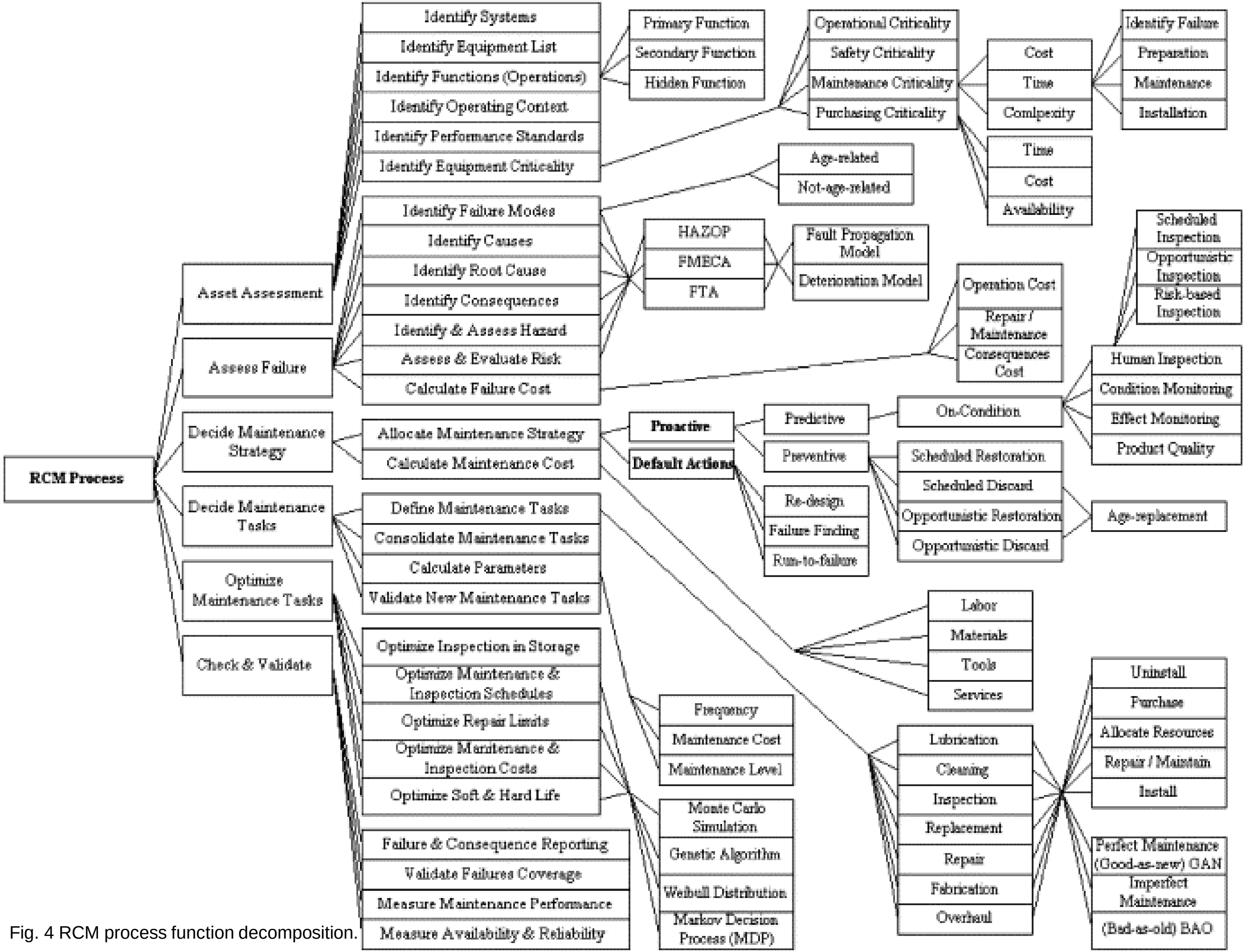


Fig. 4 RCM process function decomposition.

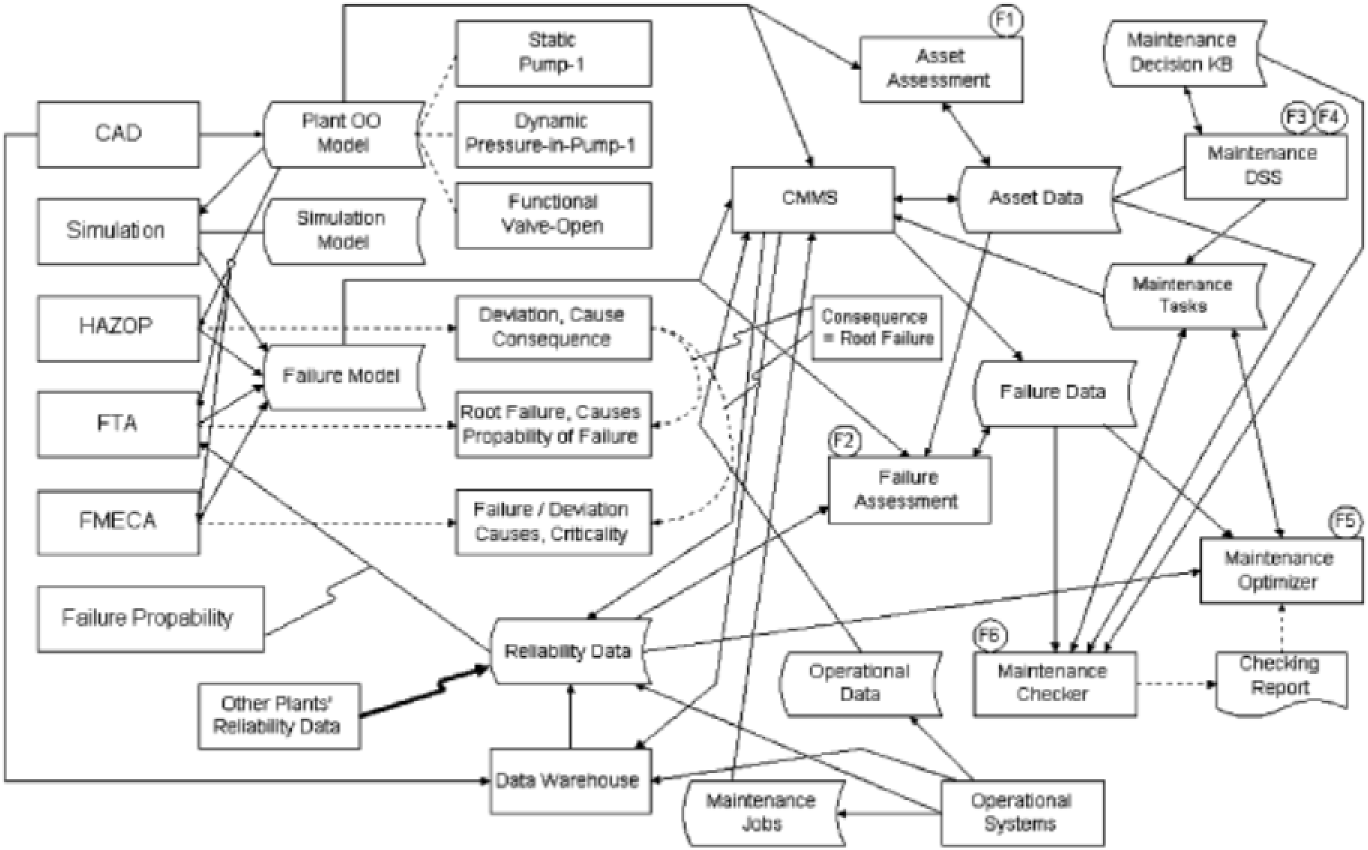
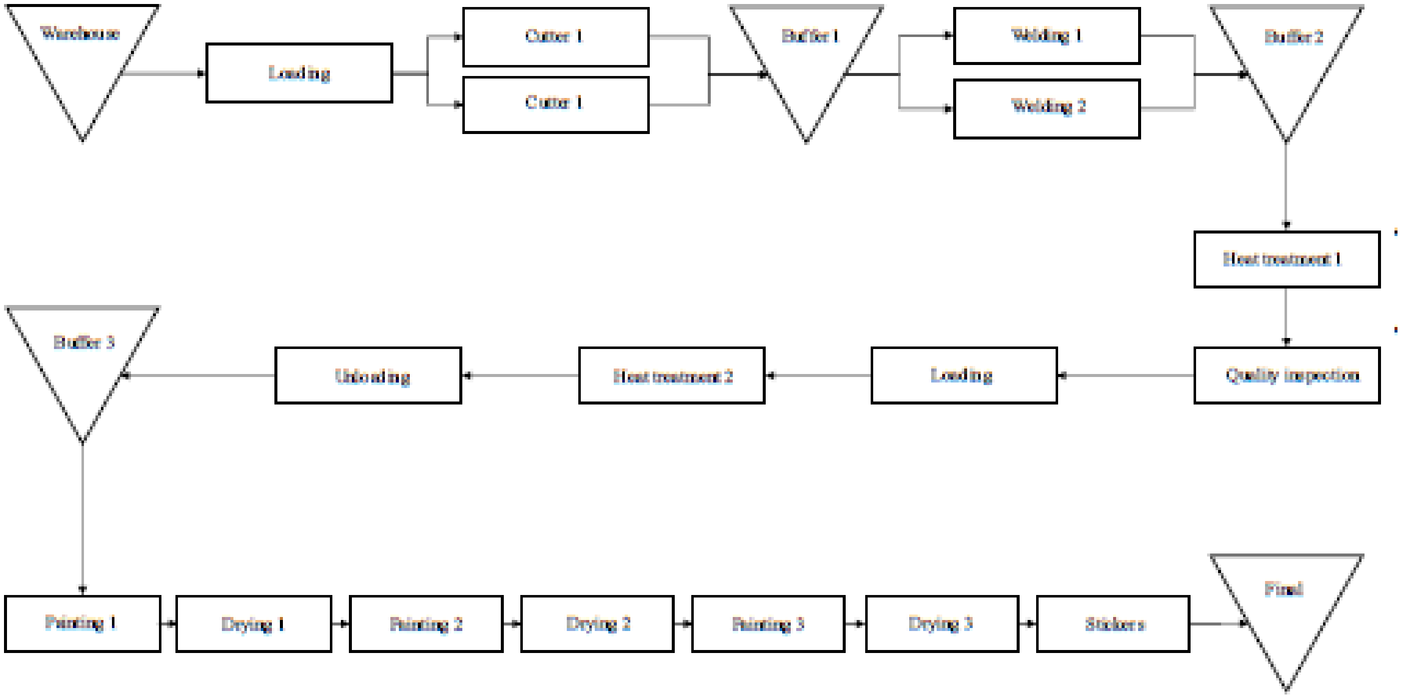


Fig. 5. Detailed system design of the proposed integrated solution.


Warehouse
Loading
Cutter 1
Cutter 1
Buffer 1
Welding 1
Welding 2
Buffer 2
Heat treatment 1
Quality inspection
Loading
Heat treatment 2
Unloading
Buffer 3
Painting 1
Drying 1
Painting 2
Drying 2
Painting 3
Drying 3
Stickers
Final

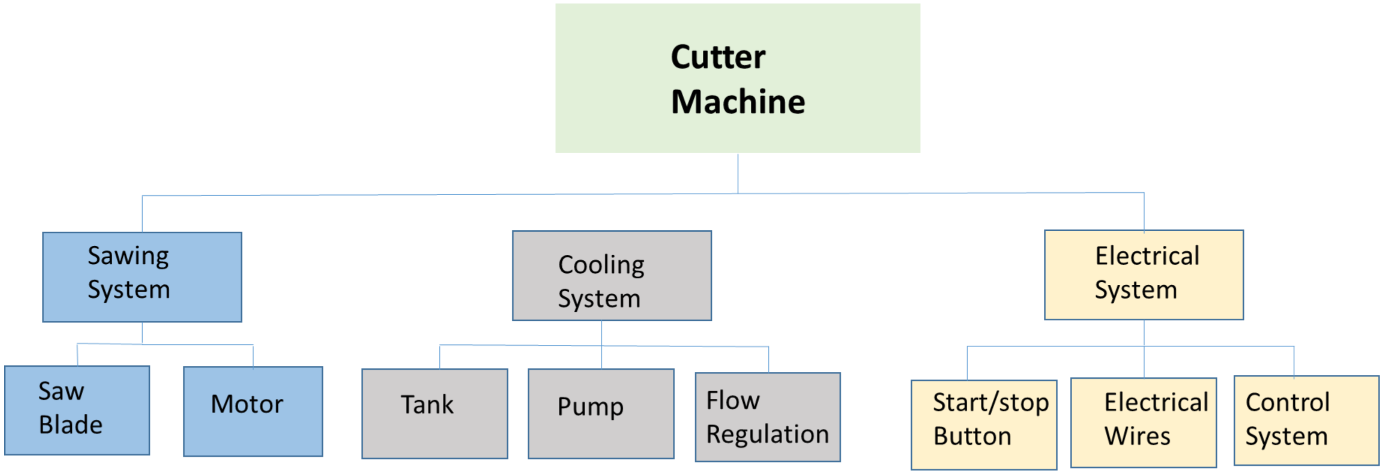
Machine descriptions for RCM

Machine: Cutting

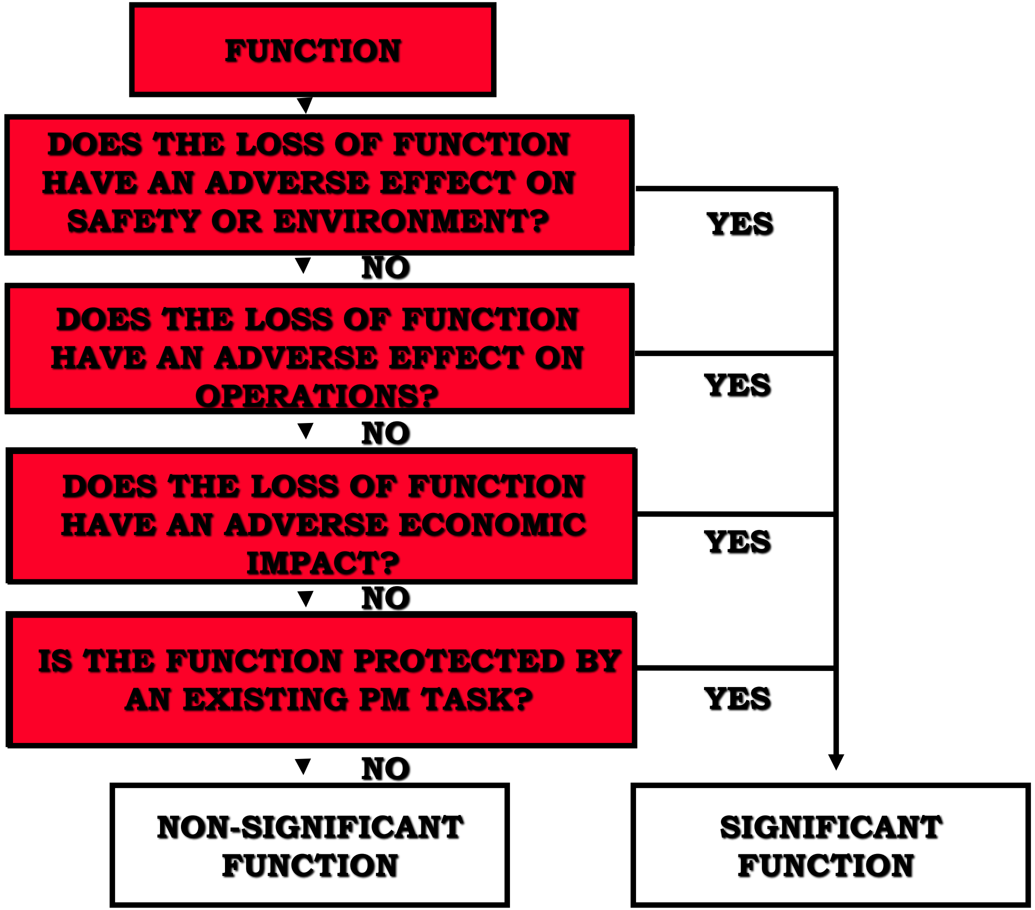
Description: The first step in the production process is to cut the raw material (aluminium tubes) into correct sizes. There are two identical cutting machines in the factory today. Replacing the saw blade is a part of the preventive maintenance work.

Important systems: Sawing, Cooling, Electrical

Vulnerable components: Saw blade, motor, tank, pump, flow regulation, start/stop button, electrical wires, control system


Cutter Machine
Sawing System
Cooling System
Electrical System
Saw Blade
Motor
Tank
Pump
Flow Regulation
Start/stop Button
Electrical Wires
Control System

SIGNIFICANT FUNCTION (SF) IDENTFCATION



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