DEBRE MARKOS UNIVERSITY
INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL & INDUSTRIAL ENGINEERING

Course Title	Maintenance & installation of Machinery
Course Code:-	MEng 5231
Credit Hours:-	3
Degree Program	B.Sc. in Mechanical Engineering
Academic year:-	2012 E.C
Year & Semester:-	Fifth year second semester
Pre-requisites:-	Senior standing course

Objective

- **The course is intended to enable the student to:-**
  Understand theoretical and practical aspects of maintenance practice in industrial setup;
- Understand basics of damages of typical components of machinery and thereby help the student realize the state of damage of machinery;
- Realize the use of the concepts of reliability, maintainability and availability in maintenance technology which are helpful in the prediction of plant performance;
- Understand the organization of a maintenance department, maintenance
- planning and decision making processes, Develop practical skill by providing some practical work of maintenance;

Chapter one
Introduction

1.1 Basics of Maintenance

MAINTENANCE FACTS AND FIGURES

- ✓Each year over $300 billion are spent on plant maintenance and operations by U.S. industry, and it is estimated that approximately 80% of this is spent to correct the chronic failure of machines, systems, and people.

- ✓In 1970, a British Ministry of Technology Working Party report estimated that maintenance cost in the United Kingdom (UK) was approximately £3000 million annually.

- ✓Annually, the cost of maintaining a military jet aircraft is around $1.6 million; approximately 11% of the total operating cost for an aircraft is spent on maintenance activities.

WHAT IS MAINTENANCE?

Maintenance: Keeping something in good condition by checking or repairing it regularly (Oxford Dictionary)

Maintenance consists of those activities required to keep a facility in original (i.e. as-built) condition so that its designed productive (or performance) capacity remains unchanged.

Maintenance can be defined as a combination of actions carried out to ***repair, replace*** or ***service*** the components with an aim to bring the servicing unit to original (or as original) condition so that it can operate designed capacity for a specified period of time.

In other words, ***maintenance*** can also be defined as follows

Maintenance is the totality of all measures directed towards control (***preservation*** and ***restoration***) of the performance of a plant.

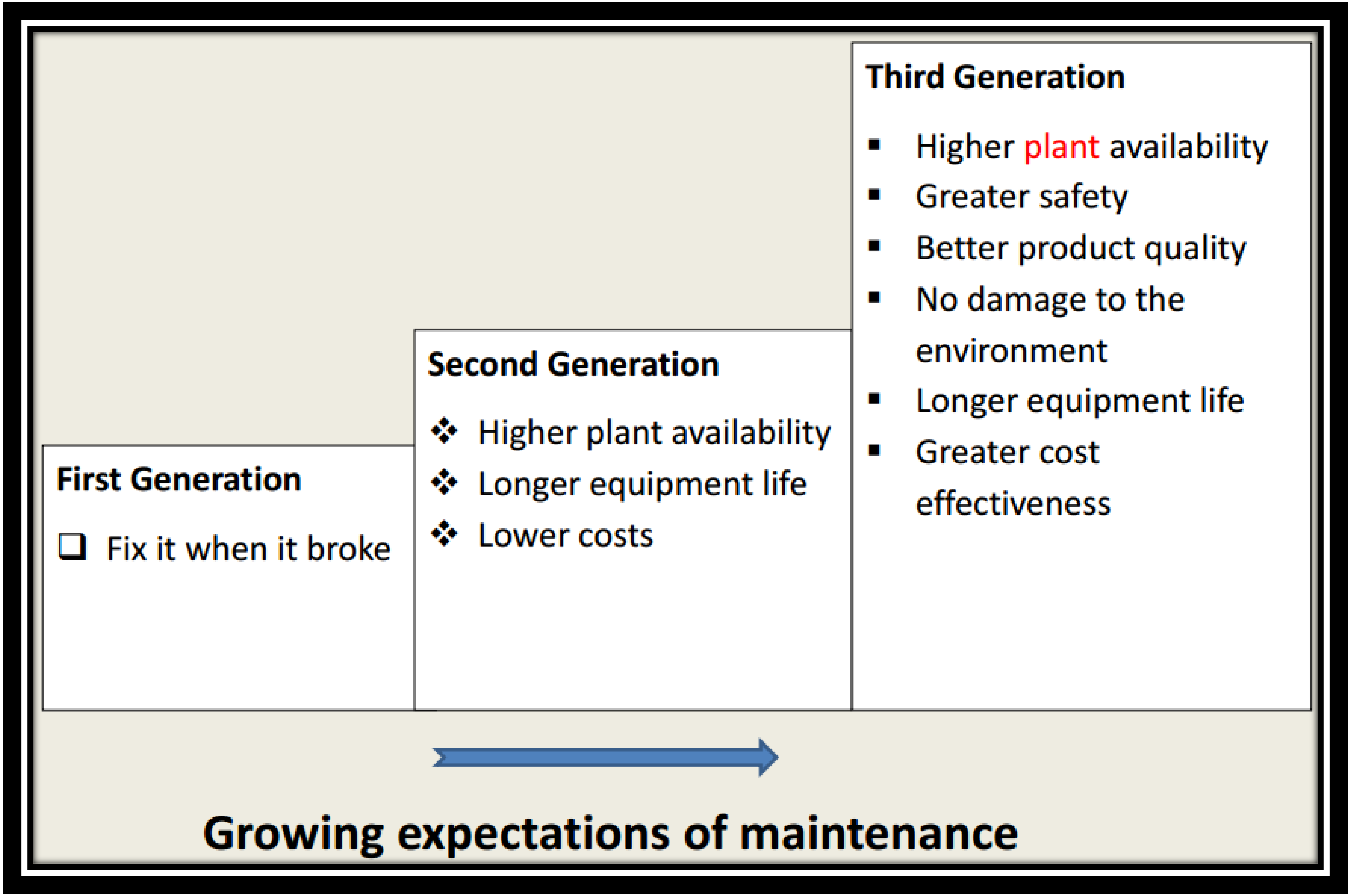
It is an auxiliary process in a production process directed towards a high effectiveness of the main process.

1.2 Trends in the Evolution of Maintenance

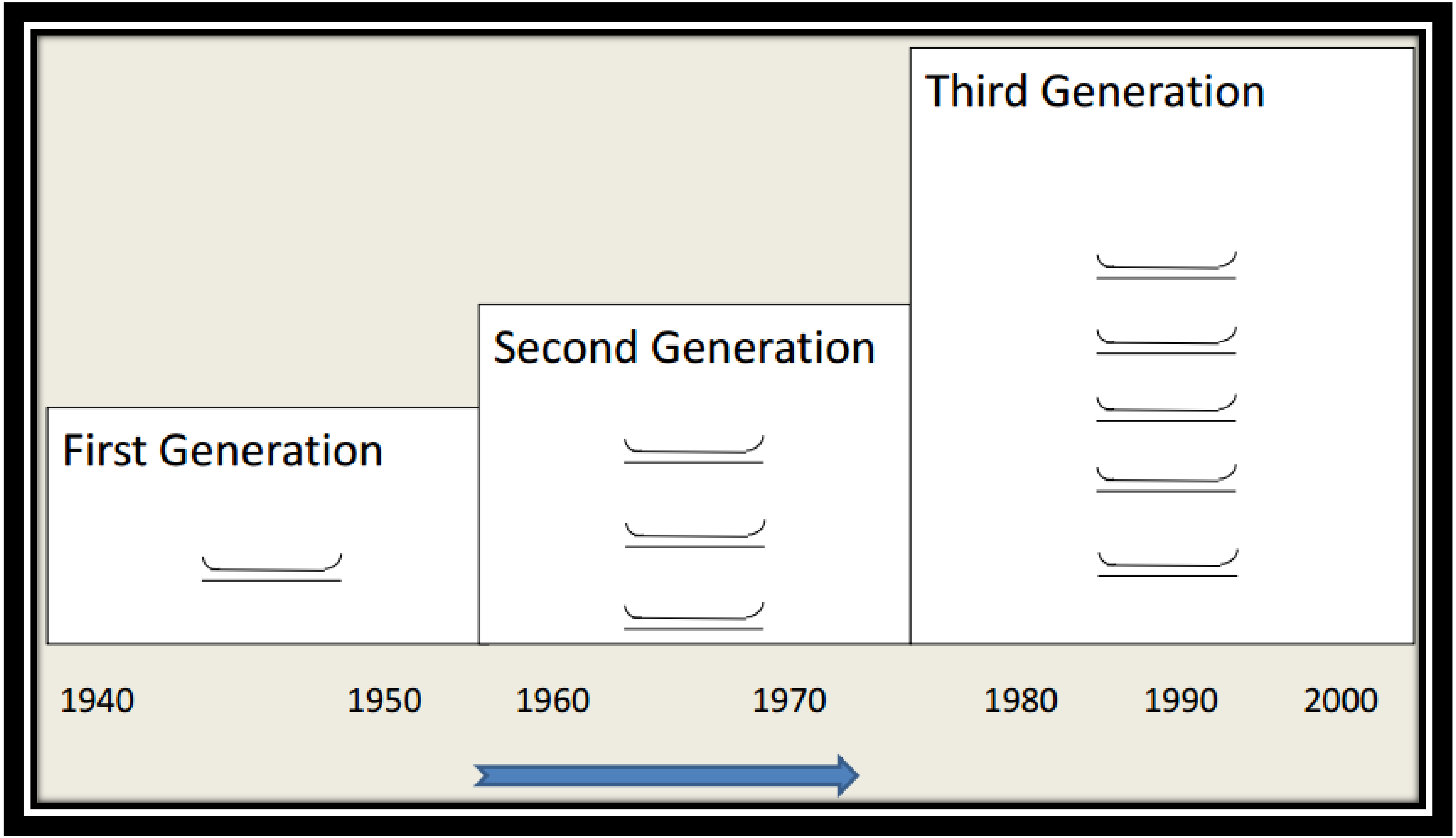
According to **John Moubray** , author of *Reliability Center Maintenance*, the evolution of maintenance since the 1930's can be traced through three generations.

The distinction between these generations depends up on basically three technical factors:

- ✓Growing expectations of maintenance,
- ✓Changing view on equipment failures, and
- ✓Changing maintenance techniques


First Generation
Fix it when it broke
Second Generation
Higher plant availability
Longer equipment life
Lower costs
Third Generation
Higher plant availability
Greater safety
Better product quality
No damage to the environment
Longer equipment life
Greater cost effectiveness
Growing expectations of maintenance

Changing view on equipment failures



Changing maintenance techniques

First Generation

- Fix it when it broke

Second Generation

- Scheduled overhauls
- Systems for planning and controlling work
- Big, slow computers

Third Generation

- Condition monitoring
- Design for reliability and maintainability
- Hazard studies
- Small fast computers
- Failure modes and effects analysis
- Expert systems
- Multiskilling and team work

First Generation

This covers the period up to the world war II. During this period:

- Industry was not highly mechanized
- Equipment Was not highly mechanized
- Downtime did not matter much
- Prevention of equipment failure did not have high priority
- Failures were corrected as they occur

As a result, there was not need for systematic maintenance beyond cleaning, servicing and lubrication.

Second Generation

During the war, demand for good increased and supply of industrial outputs was low.

This led to increase in mechanization. During this period:

- Machines became numerous and more complex,
- Industry started to depend heavily on these machines Downtime started to matter,
- The idea the equipment failures could and should be maintained came up

As a result, the concept of preventive maintenance and maintenance planning and control systems grew up.

Third Generation

Since the mid-seventies, ***new expectations, new research*** ***and*** ***new techniques*** have revolutionized maintenance. During this period:

- Maximizing life of equipment has become important
- Higher plant availability and reliability have become very important
- Greater automation has been effected
- Quality standards, safety and environmental consequences matter quite a lot
- Cost of maintenance has become central
- Greater expectations have lead to new research which in turn are leading to new techniques

1.3 Maintenance Objectives

Maintenance objectives should be consistent with and *subordinate to production goals*.

The relation between maintenance objectives and production goals is reflected in the action of keeping production machines and facilities in the best possible condition.

The basic objectives of maintenance are:-

★Maximizing production at the lowest cost and at the highest quality and safety standards.

★Reducing breakdowns and emergency shutdowns.

★Optimizing resources utilization.

★Reducing downtime.

★Improving spares stock control.

★Improving equipment efficiency and reducing scrap rate.

★Optimizing the useful life of equipment and

★Identifying and implementing cost reductions.

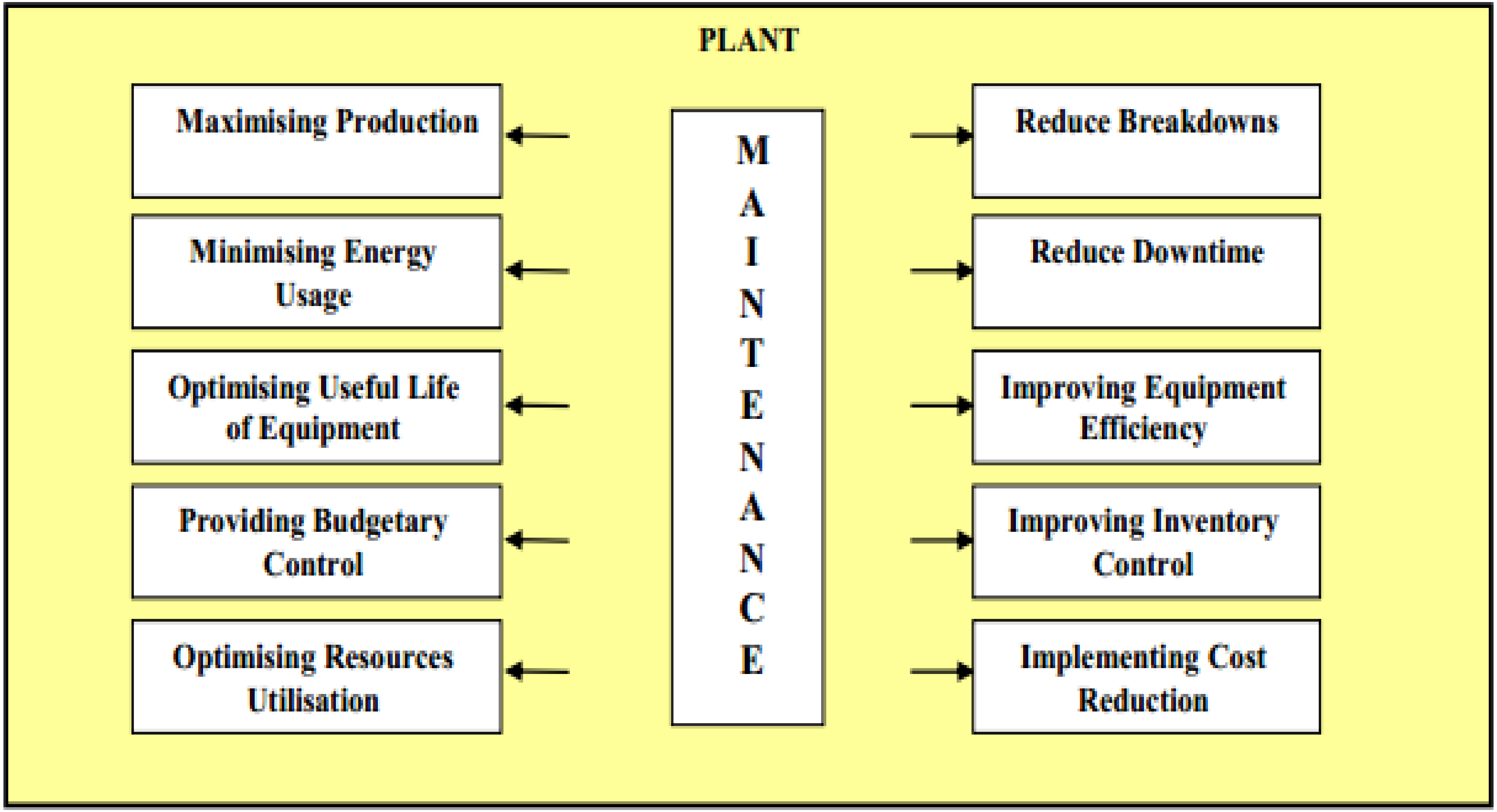


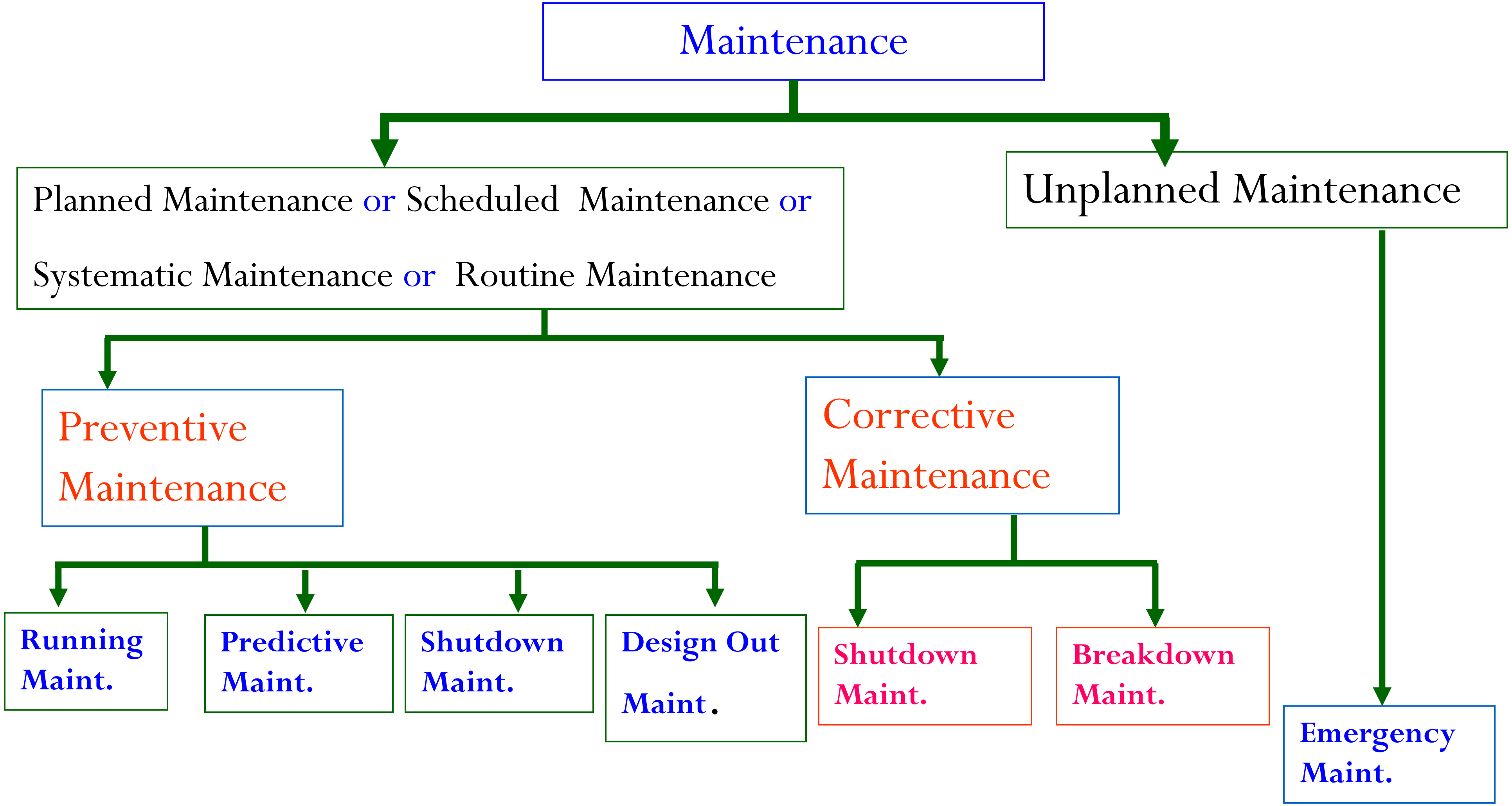
Figure Maintenance Objectives

1.4 Types of Maintenance

Different authors categorize maintenance in variety forms. The most acceptable ones is

- Planned maintenance
- Unplanned maintenance

TYPES OF MAINTENANCE



PLANNED OR SCHEDULED MAINTENANCE

It is basically done for two purposes:

i. To prevent the occurrence of breakdown and

ii. If breakdown has occurred then to restore it to original condition

A. PREVENTIVE MAINTENANCE

- Principle – “Prevention is better than cure”
- Procedure - Stitch-in-time

It is done to keep an equipment or machinery in a satisfactory operating condition through regular inspection, calibration, lubrication, overhauling, or replacement of certain components. It is action before breakdown occurs.

ADVANTAGES OF PREVENTIVE MAINTENANCE

- Reduction in downtime
- Reduction in loss of production
- Reduction in repair and replacement cost
- Fewer stand-by equipment required
- Less expenditure on maintenance personnel due to over time
- Fewer parts to be stored
- Higher safety level in the shop
- Planned output possible to maintain

Preventive Maintenance is divided into four categories

1. **Running Maintenance** is done even when the machine or equipment is in service.
2. **Shut-down Maintenance** is done when the machine is not in use.
3. **Design-out Maintenance**: Equipments are designed that no maintenance should be required or at worst least maintenance should be done.
4. **Predictive Maintenance** is done on the information received regarding the performance of an equipment or machinery.

B. CORRECTIVE MAINTENANCE

corrective maintenance:- is done to bring the machinery to original performance level, by minor adjustments of certain knobs, or key units or replacing some worn-out parts.

This could be

- Complete failure
- Minor failure

- Quite justified in small factories where:
  - Down times are non-critical and repair costs are less than other type of maintenance
  - Financial justification for scheduling are not felt

- Corrective Maintenance Could be:

1. Shutdown Maintenance
2. Breakdown Maintenance

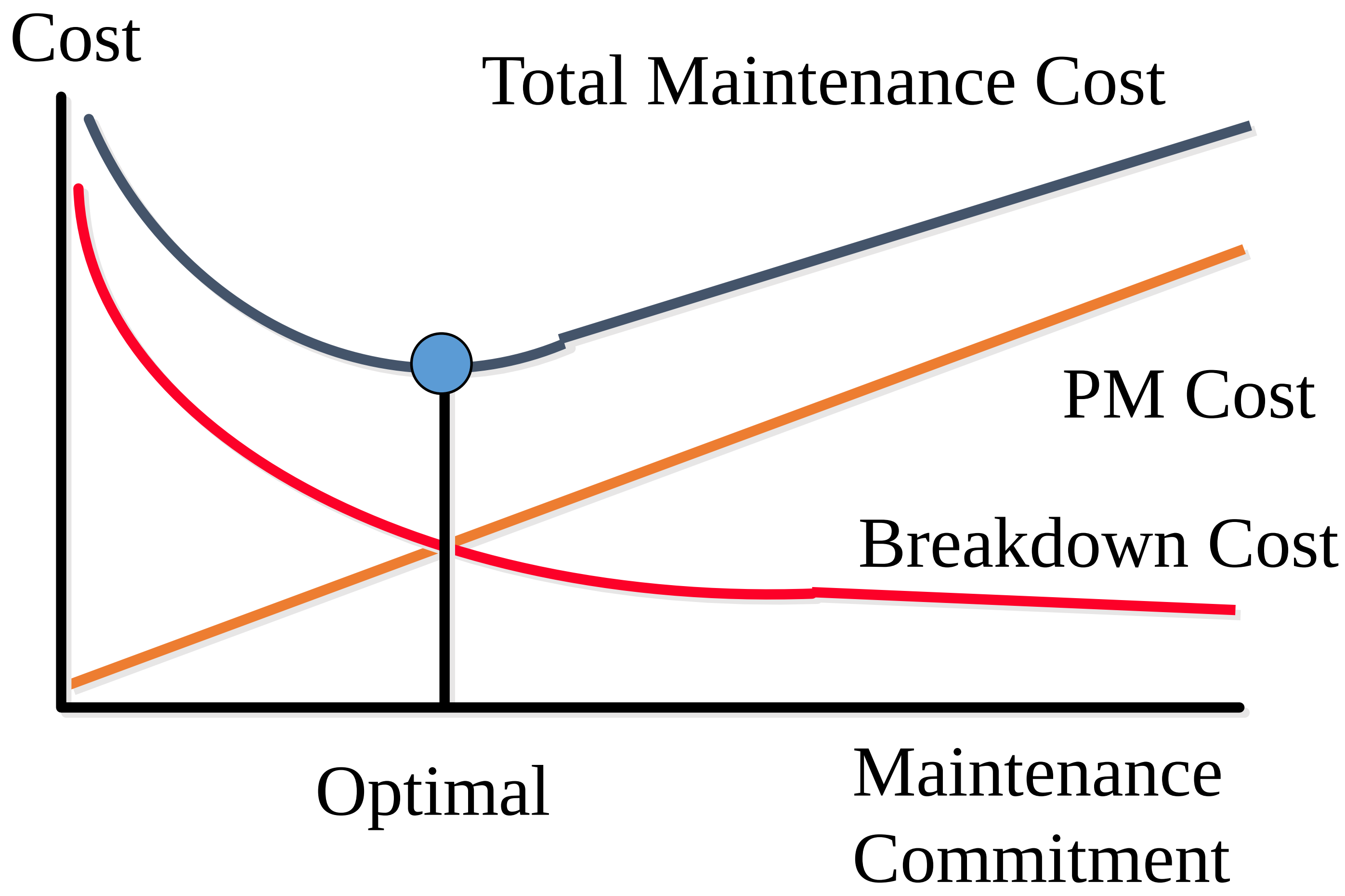
TYPICAL CAUSES OF EQUIPMENT BREAKDOWN

- ✍ Lack of lubrication
- ✍ Failure of cooling system
- ✍ Failure to replace worn-out parts
- ✍ Negligence to rectify minor faults
- ✍ Too high or too low voltage supply
- ✍ Wrong fuels used
- ✍ Uneven working parameters
- ✍ Unsound foundation, etc.

Disadvantages of Corrective Maintenance

- Breakdown generally occurs inappropriate times leading to poor and hurried maintenance
- Excessive delay in production & reduces output
- Faster plant deterioration
- Increases chances of accidents and less safety for both workers and machines
- More spoilt materials
- Direct loss of profit
- Can not be employed for equipment regulated by statutory provisions e.g. cranes, lift and hoists etc.

Maintenance Costs



1.5 Introduction to Machine Installation

Machine:

It is a device that takes some energy as input and transforms it to another useful form of energy as output.

Machine Installation:

It is the process of fixing and erecting the machinery in an industry so that they can be put to use for productive purposes

Why Machine installation is necessary?

It is the first step in the productive process of any newly established plant.

Where to install machinery?

The installation of light machinery used for domestic use may not require any expertise, where as the installation of the machinery used in the industry need attention as the performance of the machinery largely depend upon proper installation.

How to install machinery?

The installation process may differ from machine to machine and it is largely depend upon the main specifications of the machines to be installed.

Factors to be considered before installing the machinery

It is important that as much information as possible be supplied regarding the machine to be installed, this will include:

- ☞ Machine size and weights
- ☞ Any dynamic features of its operation
- ☞ Location including ground type, condition where optimal performance is required
- ☞ Vibration analysis of the machine
- ☞ Site conditions

FOUNDATION REQUIREMENTS

A. Building Foundations

Footings and foundations as having two functions:

1. ***To transfer the live and dead loads of the building to the soil over a large*** enough area so that neither the soil nor the building will move
2. ***In areas where frost occurs, to prevent frost from moving the building***

- **Dead loads** are the weight of the building materials and the soil surrounding the foundations.
- **Live loads** include the weight of people, furniture, snow, rain, and wind.

B. Machine Foundations

The main purpose of machine foundations is to stabilize the machine as well as to reduce the vibrations caused due to the operation of the machine.

The foundation thus positively influences machine vibration by reducing the amplitude of oscillation.

The first step in machine installation is to find out whether it is required to build a special foundation for installation or it is possible to use the existing floor.

Foundation Requirements for machine installation

If the existing floor, where the machinery is to be installed, does not meet the following minimum requirements, It is required to build a foundation.

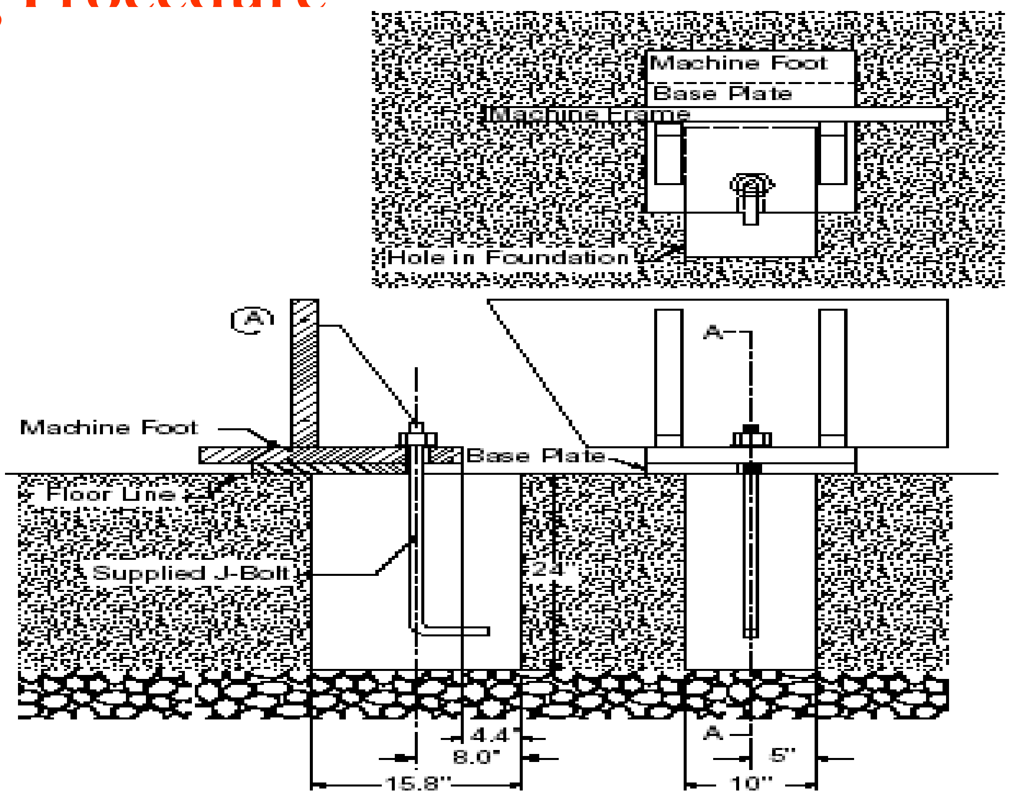
- The area of the floor where the machine frame is to be located must be a single, homogeneous slab in good condition.
- The floor must be 4" to 6" thick (It is not a constant and may change depending upon the type and weight of machinery).
- The floor must be capable of supporting 3.5 tons/ft² (This is also not a constant one and may subject to change depending upon the type of machine going to be installed and the floor must be level to 0.032"/ft).

Methods of machine installation

There are two types of machine installations in practice, which include both foundation anchoring and floor installation procedures. The following sections will explain these methods.

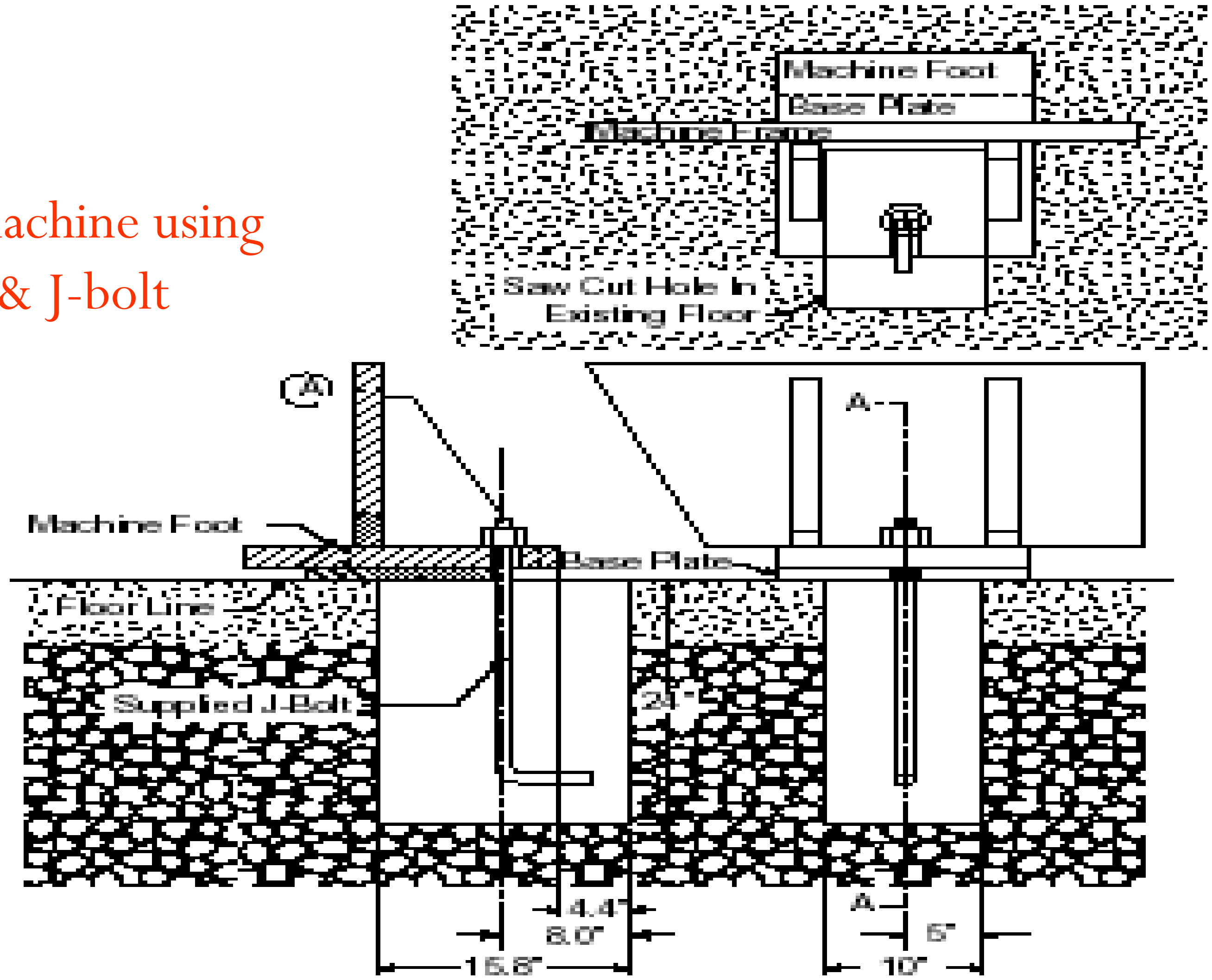
1. Foundation Anchoring Procedure

Installing the machine using foundation & J-bolt



2. Floor anchoring method

Installing the machine using existing floor & J-bolt



MACHINE LEVELING

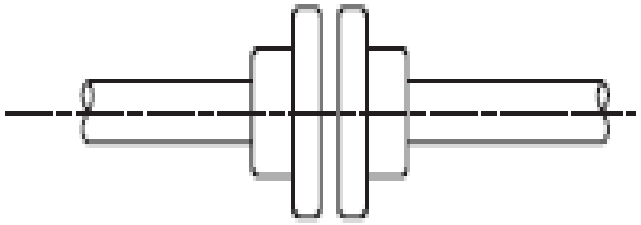
Proper Machine leveling is critical in the machine installation for the desired machine performance.

The term *leveling*, with respect to machinery installation, means the operation of placing machinery or equipment on a true horizontal plane.

The flatness of the floor plays an important step in the levelling procedure of the machine.

ALIGNMENT OF SHAFTS

Proper shaft alignment is achieved when the two *centerlines* of coupled machinery are the same or *collinear.*

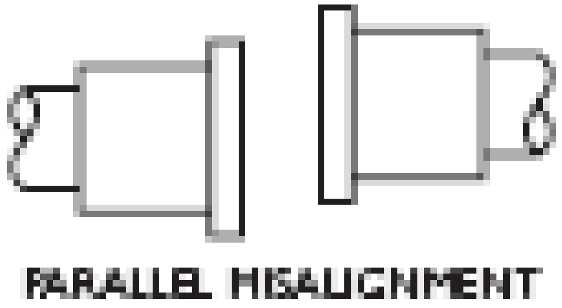


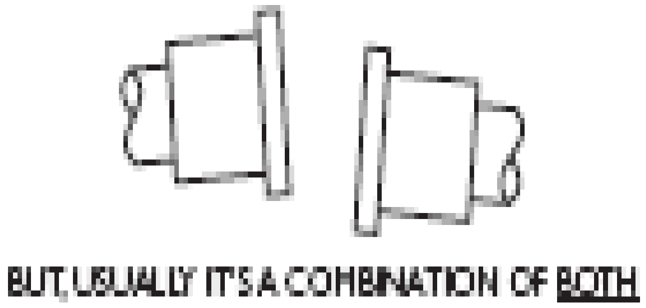
There are two types of coupling or shaft misalignment:

angular misalignment and parallel misalignment

Angular misalignment is a condition where two shaft centerlines are at an angle to each other.

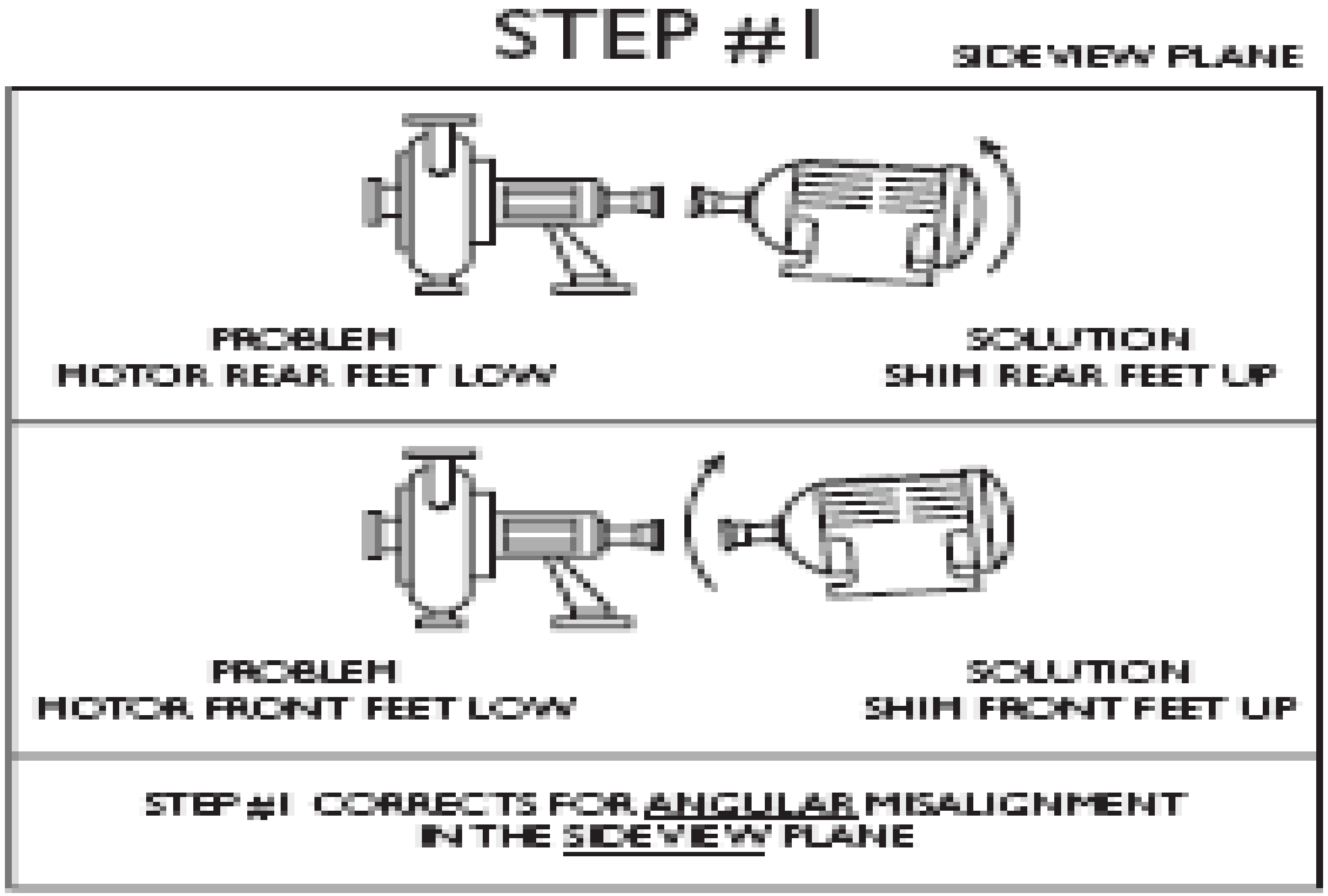
Parallel misalignment is a condition where no angular misalignment exists and the shafts are parallel, but *offset* from each other.



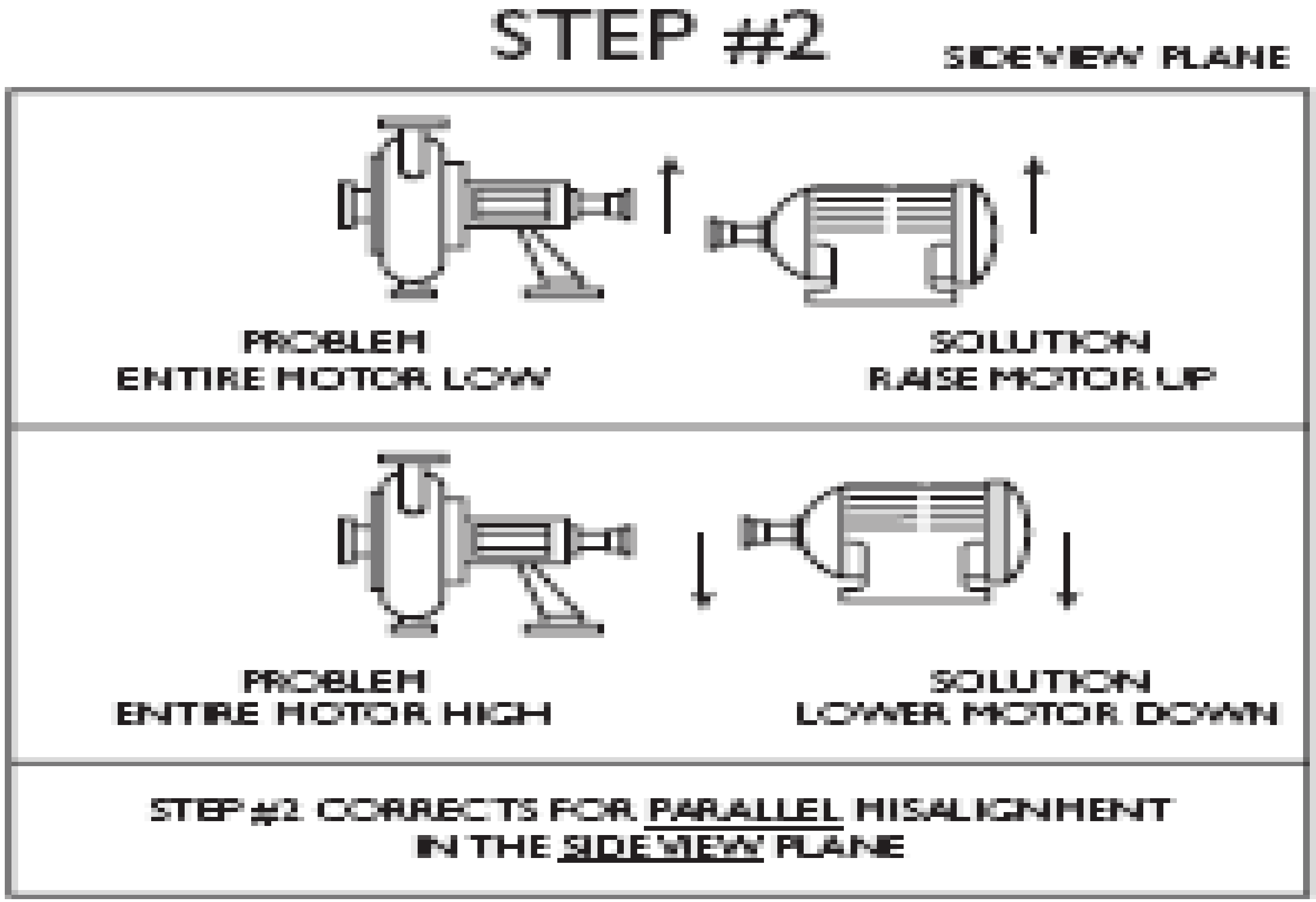


Four basic steps are required to correct misalignment:

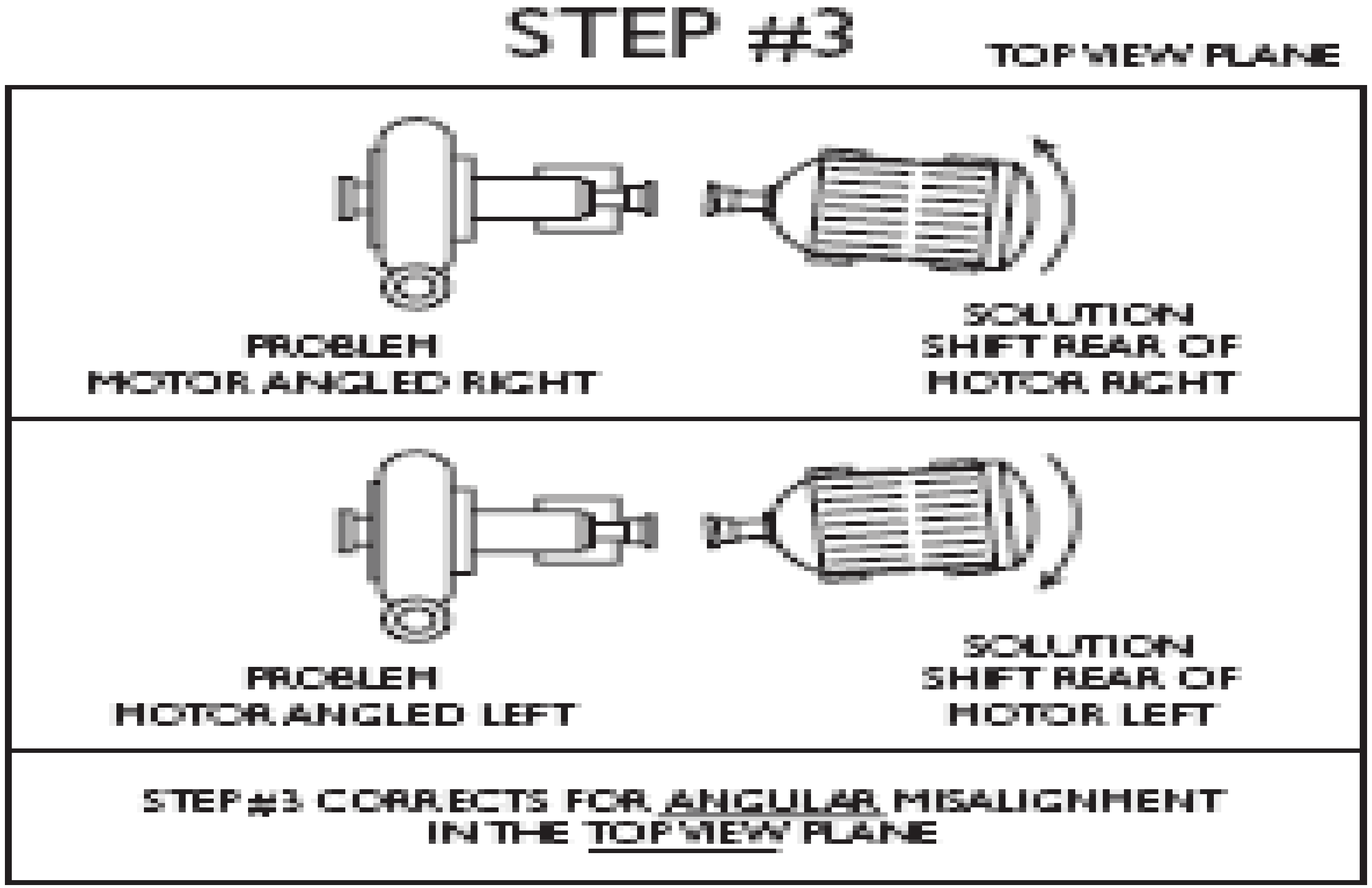
1. Correct for angular misalignment in the side view plane



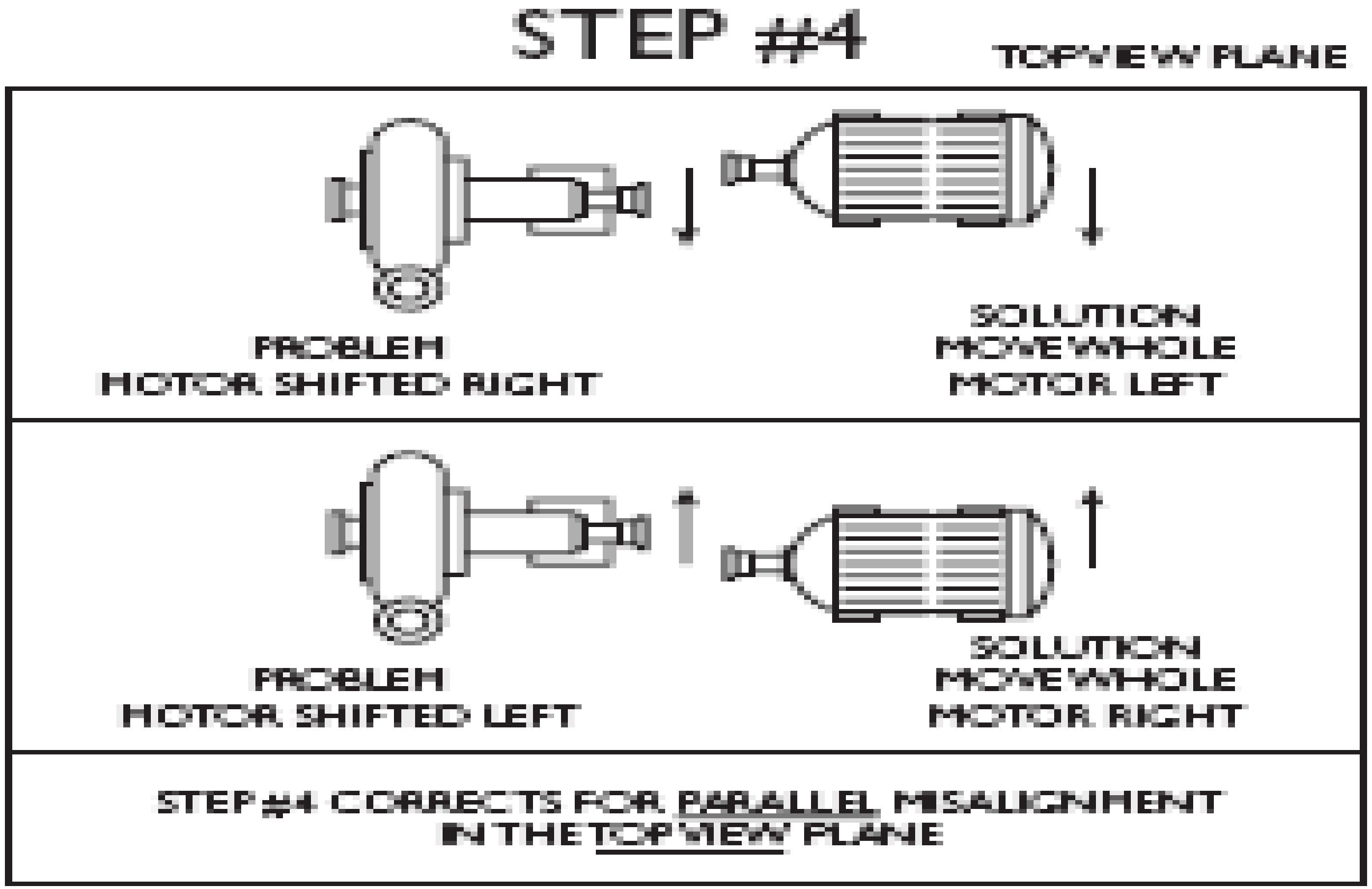
2. Correct for parallel misalignment in the side view plane



3. Correct for angular misalignment in the top view plane



4. Correct for parallel misalignment in the top view plane



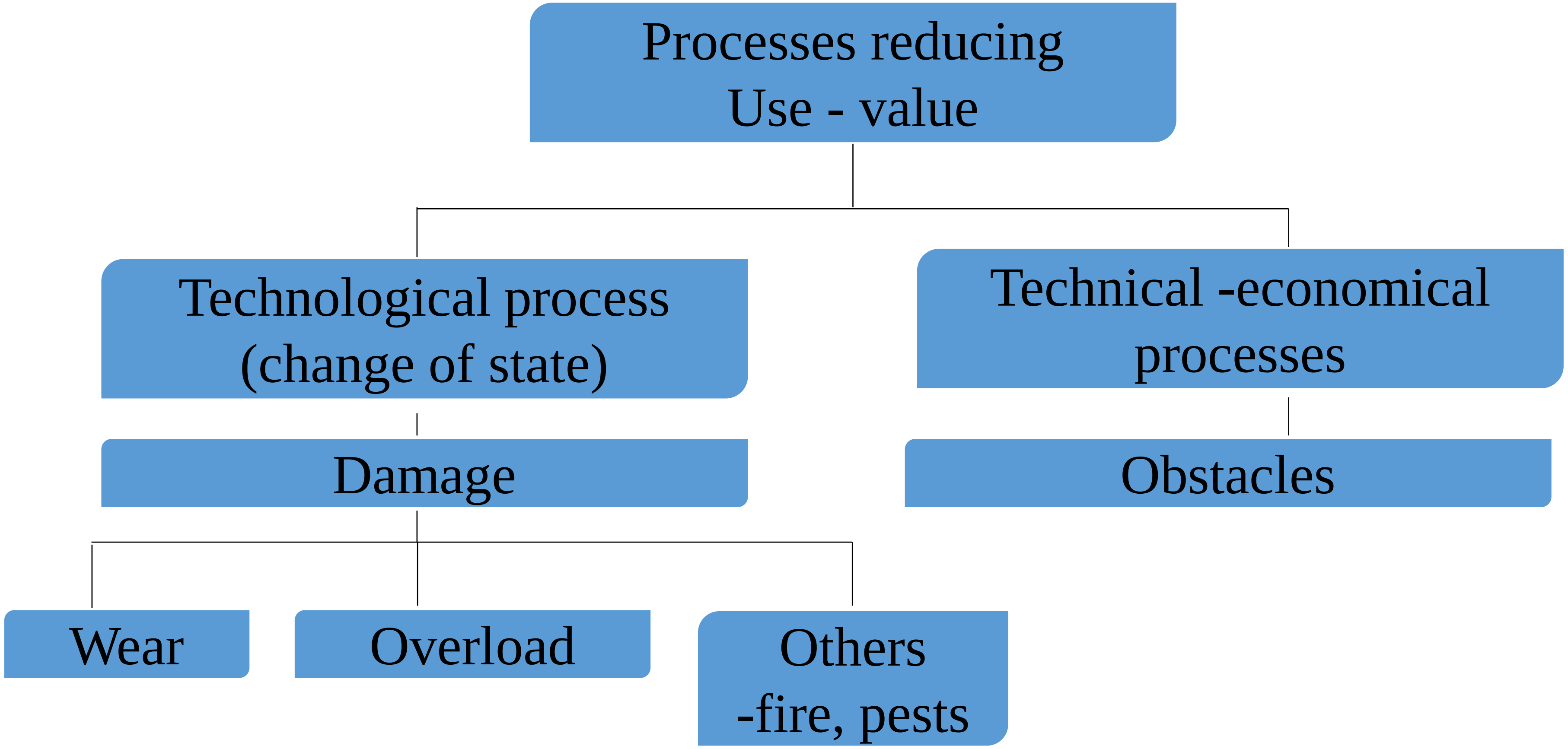
CHAPTER- 2

FUNDAMENTALS OF THE THEORY OF DAMAGES

- ✓ Damages are causes for the loss of functionability or workability of a means of production, if proper action is not taken against them.
- ✓ Even with optimum design and operation conditions damages are unavoidable.
- ✓ Thus damages are the reasons for the existence of a maintenance organization.

2.1. Classification of Damages

The use-value of equipment or a means of production is affected by two processes. These are technological processes and technical and economical processes.



2.2. Reasons of damage

- Damage is influenced by environmental conditions and conditions of use of equipment.
- For proper maintenance work, it is necessary to make systematic analysis of damages which includes discussions on reasons for damages and their consequences.
- The conclusions obtained are feedback to designers, manufactures and operational maintenance personnel.

Cont.

Reasons for damages can basically be classified as follow:-

Objective: *Those are damages caused* by operational processes and environmental causes. These damages are unavoidable.

Subjective: These are caused by failure in design, manufacturing, and maintenance.

If an equipment or a means of production is handled appropriately, subjective damages can be avoided.

2.3. Typical Damages of Equipment

The changes of state or damages result from technological processes are basically classified into three. These are; **corrosion**, **wear** and **fatigue.**

2.3.1 Corrosion

Corrosion is the destruction of materials by chemical or electrochemical reaction with the environment.

This includes the destruction of metals in all types of atmospheres, liquids, and at any temperature.

- Corrosion reduces the useful life of equipment.
- About 5% of yearly production of steel is destroyed by corrosion.
- Under most ordinary conditions of exposure, corrosion products consist mainly of oxides, carbonates and sulphids.

The processes of corrosion

- ✓The process of corrosion takes place due to direct chemical action when the metal enters into a chemical reaction with other elements to form nonmetallic compound or due to electrochemical action.
- ✓Metallic elements when placed in contact with water or a solution have definite inherent tendencies to go in to the solution in the form of electrically charged particles.

Cont.

Kinds of corrosion

Corrosion is classified by the forms in which it manifests itself,

The basis for this classification being the appearance of the corroded metal, which can be identified by visual observation

i. Surface corrosion

ii. Pitting corrosion

iii. Inter-crystalline corrosion (around the grain)

iv. Trans-crystalline corrosion (across the grain)

v. Galvanic corrosion (two metal corrosion)

Common locations of corrosion

Common locations where problems of corrosion can be found are the following:-

- ❖Along the water-line in partially filled tanks
- ❖In and around drops of water on steel surfaces
- ❖Along crack lines
- ❖Along joints, particularly in dissimilar metals
- ❖Along cold-worked areas like bending, sharp ends, etc.

Methods of minimizing corrosion

From the point of view of maintenance, damages caused by corrosion have to be dealt with preventively.

<u>Some of the methods of minimizing of corrosion are the following</u>

- Use of protective metals such as zinc, tin, lead, etc.
- Application of protective paints
- Rendering the surface of the metal passive (immersing in nitric acid after it has been highly poised immersing in fuming sulfuric acid)

Corrosion problems

Corrosion problems are pronounced, to a varying degree, in:-

- Steam generating plants
- Equipment in chemical plants
- Pipes and piping and
- Structures

2.3.2. Wear

Wear is an undesired change of surface of machine components by the removal of little particles caused by mechanical reasons and/or tribo-chemical reasons.

(tribology is the science of interacting surfaces in relative motion)

Mostly wear is ***caused by friction of two mating parts*** Thus

- There must be a pair of contacting wear partners (a basic body and a mating body)
- A normal force must act maintaining contact between the two bodies
- There must exist a relative motion b/n the two surfaces

Cont.

Kinds of wear

The whole field of wear which is diverse is divided in two limited area with similar condition

i. Depending of the relative motion of mating parts

a. Kinematic wear

- Sliding
- Rolling
- Drilling
- Mixed

b. static wear

c. Impact

ii. Depending on the time behavior of wear there are two kinds of wear:-

a. Stationary wear – in which the wear intensity remains constant

b. Non-stationary wear – in which the wear intensity depends on time

Wear processes

The wear process is a complex one being dependent on a number of factors:

- Load,
- Velocity,
- Intermediate materials,
- Ambient condition, etc.

Wear processes are accompanied by heating in the micro-range as well as changes in the physical and chemical material properties of the wear partners.

Wear processes can be differentiated as

i. Shearing process

Roughness points will be sheared off if the acting forces are greater than the shear strength. This leads to the reduction of roughness and increased percentage of contact area which reduces energy concentration and wear velocity .

ii. Elastic deformation

Big surface roughness results in low percentage of contact area and high energy concentration in contact point. This may result in high local stresses in the elastic range this causes small flattening or bending of roughness points. Repetition of this process will cause local fatigue of material.

Cont.

iii. Plastic deformation

If local stress produced exceeds the elastic limit, plastic deformation takes place in flattening and bending the material with no loss in mass.

Wear types

Depending on the presence of lubricants and/or lack of it, wear types are classified into the following.

i. Wear by solid friction

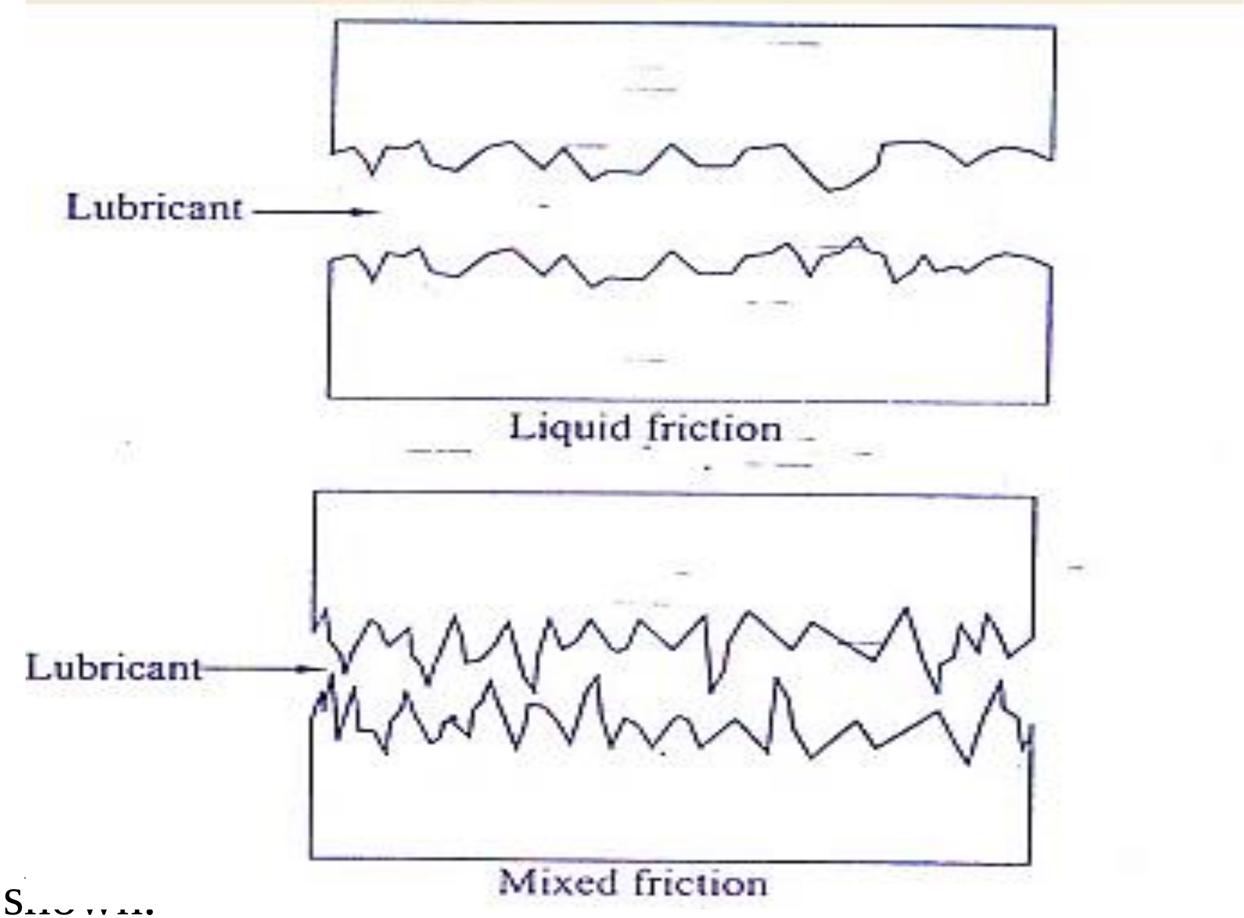
Solid friction occurs between the contacting surfaces of two bodies having relative motion where there is no intermediate material.

ii. Wear by liquid friction

In the case of liquid friction the two mating bodies are completely separated from each other by an intermediate material, mostly a lubricant.

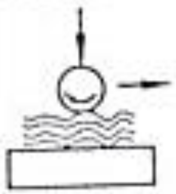
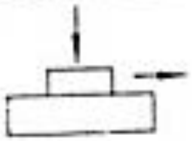
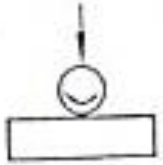
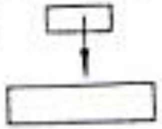
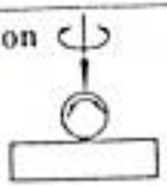
iii. Wear by mixed friction

Simultaneous action of solid and liquid friction, caused by high roughness or high load for the lubricating film causes wear by mixed friction.

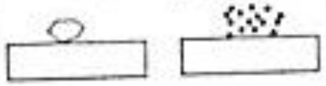
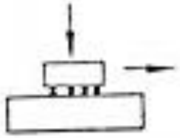
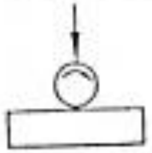
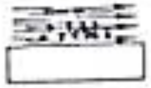
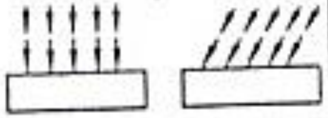
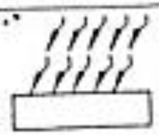


Schematically these wear types are s...

Classification of wear phenomena

System structure	Tribological action (symbols)	Type of wear	Effective mechanisms (individually or combined)			
			Adhesion	Abrasion	Surface fatigue	Tribo-chemical reactions
Solid - interfacial medium (full fluid film separation) - solid	sliding rolling impact 				X	X
Solid - solid (with solid friction, boundary lubrication, mixed lubrication)	sliding 	sliding wear	X	X	X	X
	rolling 	rolling wear	X	X	X	X
	impact 	impact wear	X	X	X	X
	oscillation 	freting wear	X	X	X	X

Cont.

Solid - solid and particles	sliding 	sliding abras[ion]		X		
	sliding 	sliding abrasion (three body abrasion)		X		
	rolling 	rolling abrasion (three body abrasion)		X		
Solid - fluid with particles	flow 	particle erosion (erosion wear)		X	X	X
Solid - gas with particles	flow 	fluid erosion (erosion wear)		X	X	X
	impact 	impact erosion (erosion wear)		X	X	X
Solid - fluid	flow oscillation 	material erosion cavitation erosion			X	X
	impact 	drop erosion			X	X

Time- behavior of wear

Amount of wear depends on time according to the equation

$h = \; ho + \; h'.t^{a}$

where

a is exponent of wear behavior ,

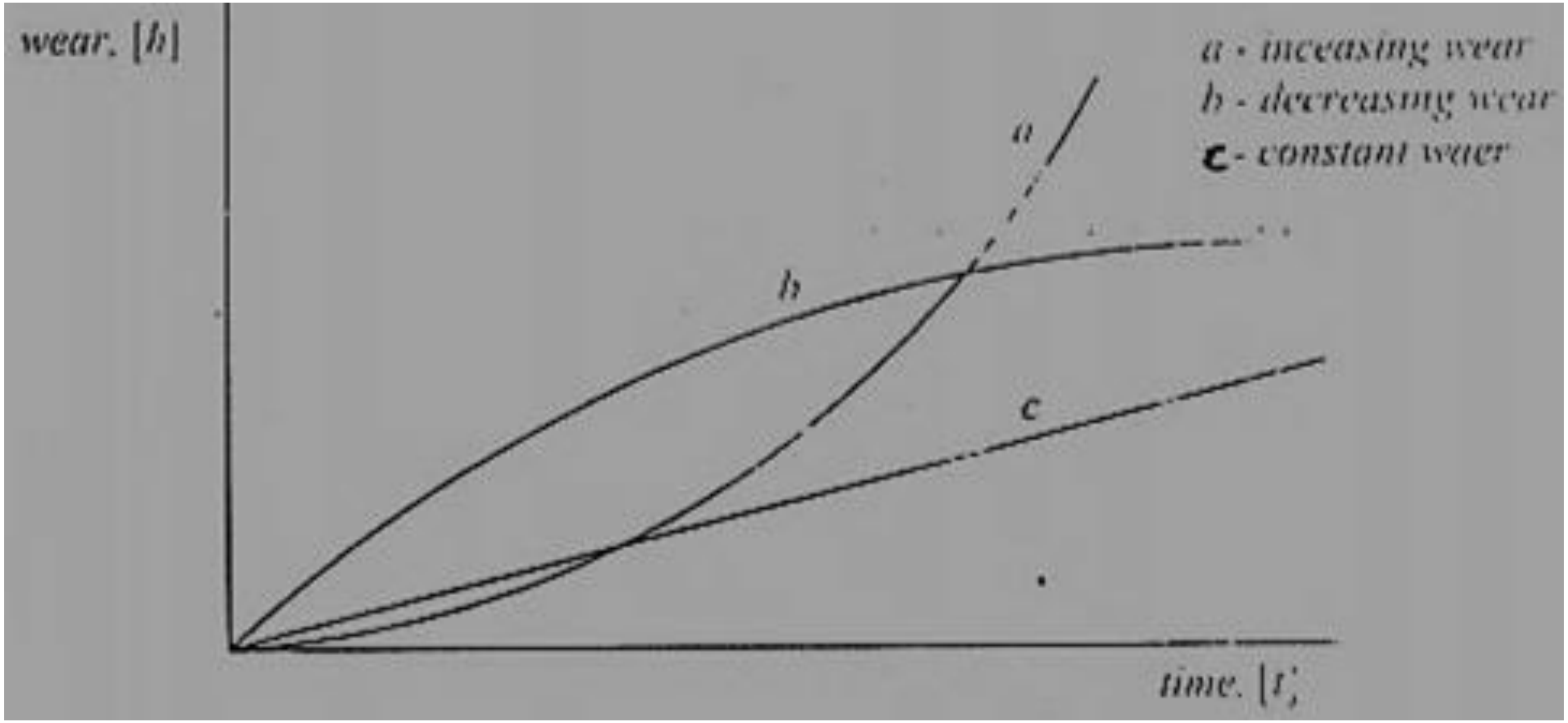
h is amount of wear,

h' is wear velocity, and

ho is the initial wear.

t is time

Depending on a, assuming the initial wear *ho* = 0, the wear behavior with time can be increasing, decreasing or constant. These three wear behaviors With time are shown in the figure below.



Protection against wear:

- The main protection measure against wear is lubricating of the moving parts.
- A lubricant is the intermediate material between two parts with relative motion for the purpose of reducing friction and/or wear between them.
- Addition/replacement of lubricant plays a vital role in maintaining machine accuracy and increasing its working life.

Classification of lubricants

Lubricants are in the form of lubricating oils, grease and solid lubricants.

i. Lubricating oils

Lubricating oils are of two types: mineral and synthetic oils.

In addition to preventing or minimizing wear, lubricating oils perform the following duties:

- ✓**Cooling** by reducing friction and removing excess heat generated
- ✓**Protection** by inhibiting corrosive processes caused by air and water
- ✓**Cleaning** by flushing dirt particles away from lubricated surfaces

A, Mineral oil:

Mineral oil is basically hydrocarbons often with some additives to introduce specific characteristic features in the oil. Mineral oils are classified as:-

- ***Paraffinic:-*** which contain significant amounts of waxy hydrocarbons with little or no asphaltic matter;
- ***Naphthenic:-*** which contain asphaltic matter in fraction, with little or no wax;
- ***Mixed base:-*** which contain asphaltic materials

Cont.

The most important physical property of mineral oils is viscosity which is a measure of resistance to flow .

Other important lubricant properties are the following

- ⌘Anti-wear and EP (extreme pressure) properties
- ⌘Oxidation resistance
- ⌘Anti-corrosion properties
- ⌘Anti-foaming property; and
- ⌘Ability to separate from water

B, Synthetic oils

Synthetic oils are products produced under controlled conditions from chemical base and additives.

Synthetic oils are engineered to perform under rigorous conditions and extreme temperature.

The most important properties of synthetic oils are the following

★Added lubricity

★Higher film strength

★Good engine start-up properties

★Good resistance to thinning:

★Improves energy efficiency

★Less sludge or deposit formation

★Good thermal properties:

Cont.

Because of their properties, synthetic oils are used for high speed lubrication under extreme loading conditions.

However, synthetic oils have some disadvantages and these are:

- ☞Compatibility problem with paints, elastomers and certain metals;
- ☞Reactive in the presence corrosion;
- ☞High potential for toxicity;
- ☞Disposal problem due to un-degradable molecular structure;
- ☞More expensive;

ii. Greases

Grease may be defined as:-

solid to semi-fluid lubricant consisting of a dispersion of a thickening agent in a lubricating fluid.

Depending on the degree of consistency, greases are classified as:-

Semi-fluid, Soft and Stiff

In selecting grease for use, considerations must be given to conditions and nature of use including:-

i. The first thing to be decided is the consistency range.

ii. Next comes the operating temperature.

iii. Use of greases is limited to very low speeds up to 2m/s.

iii. Solid lubricants:

- ✓A solid lubricant is defined as any solid used as powder or a thin film on a surface to provide protection from damage during relative motion so as to reduce friction and wear .
- ✓Solid lubricants are used when fluid lubricants. i.e. oils and greases, are undesirable or ineffective.
- ✓Fluid lubricants are undesirable if they are liable to contaminate product as in food machinery, electrical contacts, etc.
- ✓Fluid lubricants are ineffective in hostile environments, high temperatures and extreme pressures.
- ✓A common type of solid lubricant is graphite.

<u>The following are some properties of solid lubricants:</u>

- ✍Solid lubricants are incapable of carrying away heat.
- ✍Solid lubricants are immobile and they must somehow be bonded to the surface.
- ✍Solid lubricants are capable of retaining their lubricating effectiveness at high temperatures.

2.3.3. Fatigue

- Fatigue is the failure (or reduction in strength) of a material under fluctuating stresses, which are repeated a very large number of times.
- Fatigue failure begins with a hair-line crack which develops at a point of discontinuity in the material (notches, groves, fillets,…). Once a small crack develops, it propagates under load to cause failure.
- Components subjected to fluctuating forces must be designed for fatigue conditions. Surface conditions, residual stresses due to metal working processes or metal – treating processes, stress concentration affect strength very much. Hence, they should be considered properly at design stage.
- Fatigue strength (the endurance limit) of materials is greatly decreased by the presence of a corroding medium.

Chapter Three
Typical Damages of machine parts

3.1. Sliding Bearings

The damage in sliding bearings is **wear plus fatigue**

- Static loads cause wear whereas dynamic loads cause wear plus fatigue.
- In cases where lubricant contains corrosion stimulating substances like acids produced by aging lubricant, water leaking in lubricant, etc. , corrosion also becomes an important damage.

Cont.

But when dealing with damages of the system, the whole system has to be considered especially with respect to:-

☞Alignment and shape of bush hole or bore,

☞Lubricating, and

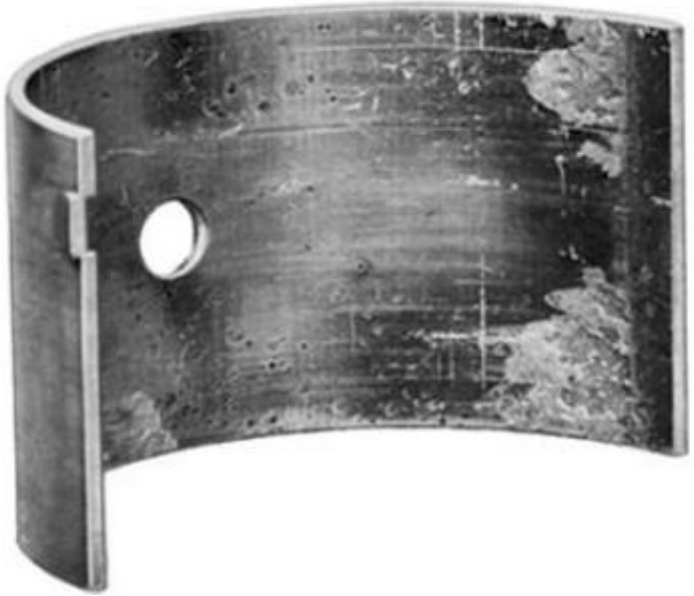
☞Deformation of shaft under applied loads.

Cont.

The process of wear depends on:-

- ✓wear velocity and operation conditions, particularly, temperature.
- ✓High temperature and high wear velocity produce overheating which change the properties of the material.
- ✓Presence of foreign substances in the lab. causes increased wear velocity.

Example



Bearing failure	Characteristics	Causes
Scoring or erosion	✓ Bearing surface is eroded in the direction of motion	✓ Excessively contaminated lubricant by non-metallic dirt exceeding the minimum oil film thickness- which roll between surfaces
Wiping	✓ Bearing surface melts, especially, for materials with low-melting point	✓ Inadequate clearance ✓ Insufficient supply of lubricant ✓ Overheating ✓ Excessive load ✓ Distorted bore
Fatigue	✓ Random cracks on bearing surface ✓ Loss of area of lining	✓ Excessive dynamic loading causing reduction in strength ✓ Overheating ✓ High speeds causing excessive centrifugal forces
Fretting	✓ Welding or metal pick-up from the bearing housing ✓ Vibration from external sources causing damage while journal is stationary	✓ Inadequate interference fit ✓ Improper housing design ✓ Small sliding movements under operating conditions
Corrosion	✓ Formation of hard deposit on surface of white-metal lining ✓ Deep pitting and attack on copper-base alloys	✓ Formation of organic acids by oxidation of lubricant ✓ Electrolyte in oil ✓ Attack by sulphur compounds from oil additivse or

3.2. Anti - friction Bearings

Roller and ball bearings

☞Ball and roller bearings normally fail by fatigue.

☞In the case of tightening and lubrication problems, wear also can occur

☞Rarely failure can occur by random damages like overload

High contact pressure causes damage of inner and outer races.

In case of over load and assembly problems failure takes place in a short time.

Cont.

Wear of bearing elements increases axial and radial play, which can be a cause for vibration leading to increased fatigue.

Analysis of damage

Due to damages bearings will either get heated up or will run with abnormal noise and/or vibration.

Anti - friction bearing defects can be any one or combination of the following:-

- Bearing inner race loose on shaft,
- Housing bore loose on shaft,
- Bearing running dry and
- Miss-alignment.

Avoid it!!!

  - Using sleeve,
  - By undergoing knurling,
  - Welding and
  - Chromium plating.

Examples

Caused due to miss alignment

Thrust bearing

Characteristics of damages in Anti Friction bearings

Damage characteristics	**Reasons for damage**
1. Running out of roundness	✓ Damage at the rings (pitting, rippling) ✓ Contamination ✓ roundness Too much bearing clearance
2. Uncommon running noise 2.1. howling, whistling	Too small bearing clearance
2.2. Unequal noise: rattling, scrabbling	✓ Too big bearing clearance ✓ Damage on racing tracks (pitting, toughening, impressions) ✓ Contamination ✓ Too viscous lubricant
2.3. gradual change of noise	✓ Changing of effective bearing clearance (caused by change in temperature ✓ Fast fatigue process ✓ Fast arising of impressions
3. High temperature 3.1. Overheating	✓ Too small bearing clearance ✓ Insufficient lubricant ✓ Excessive lubricant
3.2.Sudden increase in temperature	✓ Lack of lubricant ✓ Fast arising of pitting

Preventing the damage using lubricant

Bearings may be lubricated with grease or with oil depending on working temperature, Speed, load, bearing design and housing design. The general guidelines for use of lubrication in bearings are outlined below:-

Grease is used for:-

- ✓Low temperature up to 120^0c
- ✓Lower speed factors up to 300,000 [$mm\ rev/min$],
- ✓Low to moderate loads
- ✓Radial ball and roller bearings, and
- ✓Relatively simpler housing design.

Oils are used

✓For bearing temperature above 120^0C,

✓With higher speed factors up to 500, 000 [$mm\ rev/min$]

✓For all types of bearing designs, and

✓Complex housing design.

Generally, the grease should not fill more than three-quarters of the total available free space in the cover.

When oils are applied to lubricate bearings, bath or splash system may be used for low speeds; pressure calculating and oil mist systems are used for high speeds.

3.3 Gear Damages

A gear pair has not failed until it can no longer be run.

This condition is reached when any one or both of the following has occurred:-

- One or more teeth have broken away preventing transmission;
- Teeth are so badly damaged or worn-out that unacceptable vibration and noise are set up when the gear runs

Typical failures of gear

Gear failure	Characteristics	Causes	Remedies
1. Surface fatigue (pitting)			
a. Progressive Pitting	➢ Pits continue to form with persistent running ➢ Rapid increase may large pieces of teeth breaking away ➢ Continuous line of pitting reduces bending resistance in the affected tooth	Over-stressing of gear Material	Remove cause of overload (e.g. correct alignment)
b. Deddendum attrition	➢ Dedendum covered by a large number of small pits (with mat appearance) formation of a step at the pitch after a continued running	Possibly vibration in the gear unit	Use of more viscous lubricant

Cont.

2. Scuffing			
a. Light scuffing	✓ Tooth surfaces appear dull and slightly rough in comparison with un-affected areas ✓ Wear in the direction of sliding at the tip and root of the engaging teeth	✓ Disruption of the lubricant film with the gear tooth surfaces temperature reaching critical temperature of lubricating oil	Use of high grade oils with higher temperature
b. Heavy scuffing	Tooth surfaces severely roughened as a result of unchecked adhesive wear	Use of low viscous oils Shortage of lubricant	Avoid repeated light scuffing
3. Abrasive wear			
a. Foreign matter in oil	Grooves are cut in the tooth flanks in the direction of the sliding	Dirt falling in an open gear Inadequate initial gear cleaning ✓ Dislodged scale in oil supply pipes	✓ Use clean lubricant Prevent dirt from entering system periodic flushing

Examples

Figure 3 — Fatigue crack in a gear tooth root fillet.

Repair of transmission gears

1 Un-uniform tooth wear on one side-Turn over by 180^0

- So that the other face would be the working face.

2 Broken teeth

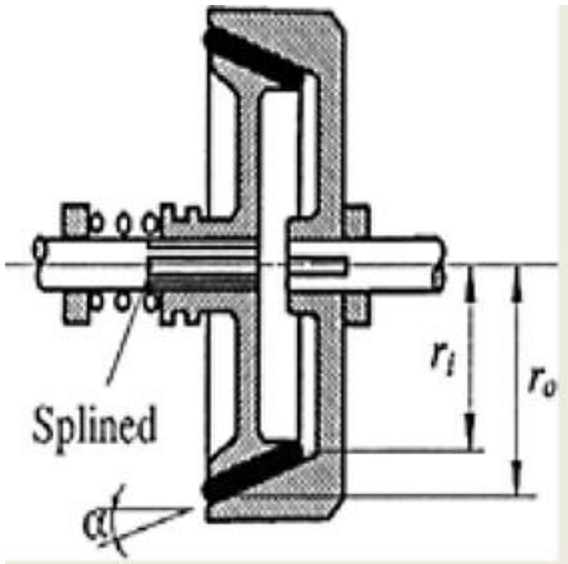
-Weld using template

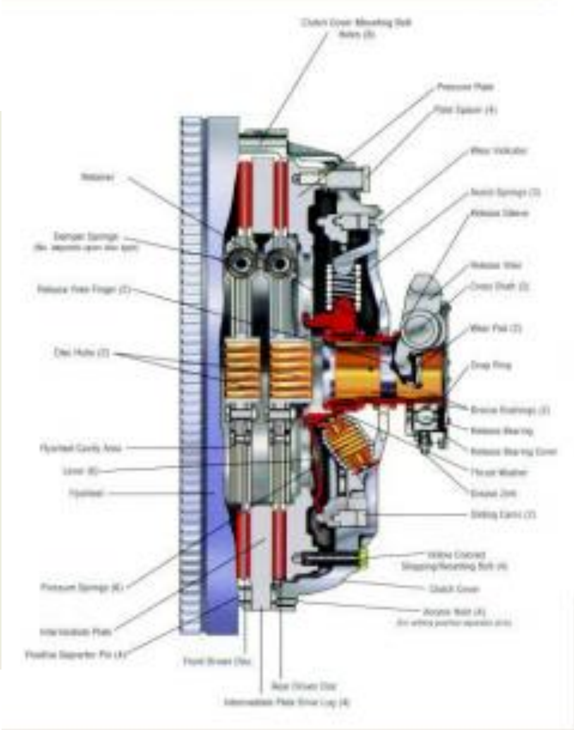
3 Cracked/damaged rim or bore of gear wheel

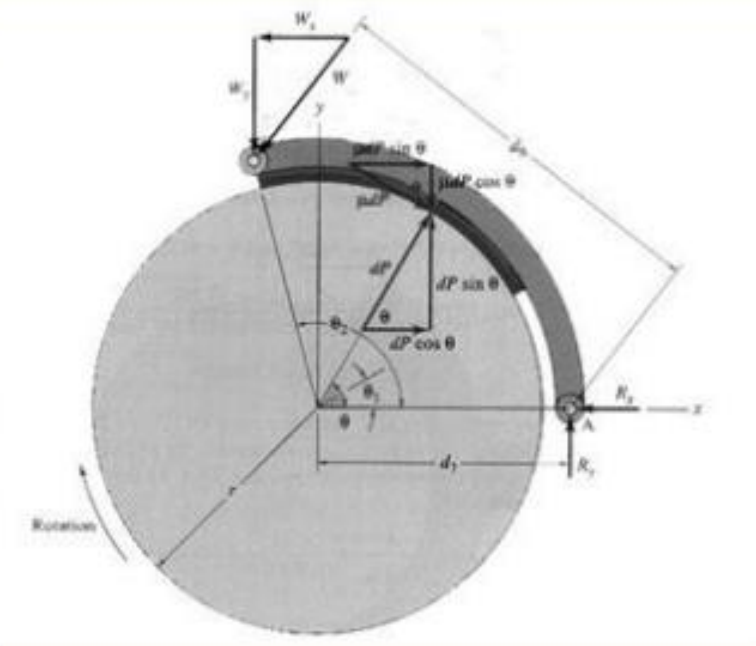
- Replace or weld the rim

3.4 Damages of friction surfaces

Friction surfaces of clutches and brakes usually fail by wear and/or deformation.







Typical clutch typical brake

Brake damages

Brake metal surface failures, their characteristics and causes

Failure	Characteristics	Causes
1. Heat spotting	Heat spotted areas with reddish brown color	❖ Distortion causing heavily loaded contact on a small area ❖ Uncomfortable mating
2. Crazing	Randomly oriented cracks on the rubbing surface of mating component	❖ Overheating ❖ Repeated stress cycling from comp. to tension (heating and cooling)
3. Scoring	Scratches of the rubbing path in the line of movement	❖ Too soft metal for the friction material ❖ Abrasive material embedded in the lining material

Cont.

Failure	Characteristics	Causes
1. Fade	✓ Material degrades or flows at the friction surface resulting in decreased and loss in performance	✓ Over heating caused by excessive braking or brake dragging
2. Metal pickup	✓ Metal plucked from the mating member and embedded in the lining	✓ Unsuitable combination of materials
3. Grab	✓ Linings contact at ends only ✓ Noisy brake ✓ Erratic performance	✓ Incorrect radiating of lining (fault in assembly)

Clutch damages

Clutch failures, their characteristics and causes

Failure	Characteristics	Causes
1. Buckling	▪ Clutch plates become buckled into a wavy pattern ▪ Preferential heating occurs ▪ Thermal damage and failure	▪ Lack of comformability (inner areas hotter than outer area causing shrinkage)
2. Material transfer	▪ Friction material adhering to opposing plate giving rise to excessive wear	▪ Overheating ▪ Unsuitable friction material
3. Bond failure	▪ Material parting at the bond to the core diate causing loss in performance	▪ Poor bonding ▪ Overheating, the high temp affecting bonding agent
4. Grooving	▪ Grooving of the facing material on the line of movement	▪ Material transfer to apposite plate

3.5. Shaft failures

- ✓shafts are subjected to various loading condition and experience tension, compression, bending or any combination of these loading conditions
- ✓These loads can be stationary or may vary with time.
- ✓The basic causes of shaft failures are wear, fatigue and misalignment.

3.5.1 Shaft failures due to wear

- Wear is a common cause of shaft failures. The wear process takes place by abrasive wear mechanism which is followed by removal of material from the surface of the shaft.
- Abrasive wear reduces shaft size and destroys shape of the shaft and causes shaft failure.

3.5.2 Fatigue failure

- ❑One of the more common causes of shaft failure is fatigue.
- ❑Fatigue failures commonly initiate at stress raisers.
- ❑The mechanism of **fatigue requires the simultaneous presence of three things:-**

⌘There must be cyclic stresses on the shaft;

⌘These stress must be tensile in nature, and

⌘There must be plastic strain.

Cont.

The process of fatigue is considered to consist of three stages:-

- Initial fatigue damage involving plastic strains leading to crack initiation;
- Crack propagation that continues to grow across the part until the remaining cross section of shaft becomes too weak to carry the imposed loads: and
- Final and sudden fracture of the remaining cross section, due to overload

Cont.

Some typical shaft features that act as stress raises are

– Corners, fillets, notches, etc.

– Key-ways, grooves, splines, etc.

– Press or shrink fits

– Welding defects,

– Metallurgical defects introduced by metal working such as forging, machining, heat treating, etc.

Others service-related factors that are important factors in fatigue initiation are damages caused by corrosion and wear

3.5.3 Shaft failures due to misalignment

Another common cause of shaft failures is misalignment. Misalignment can be introduced due to following problems:-

★Mismatching of mating parts,

★Original assembly error of equipment,

★Any maintenance activity resulting in maintenance induced alignment problems,

★Deflection or deformation of supporting components,

★Deflection or deformation of the shaft itself.

Remedies of shaft failures

Some of the remedies for preventing shaft failures are the following:-

☞by using proper lubrication.

☞Misalignment can be eliminated by proper assembly procedures.

☞Fatigue can be reduced by proper design of local areas known as stress raisers.

☞Avoiding sharp surfaces during machining as much as possible eliminates the formation of stress raisers.

☞Use of proper fits and tolerances reduces misalignment, wear and fatigue.

3.6. Seals

Basic seal types and their characteristics :-

✍**Dynamic seals**

Between surfaces in sliding contact or narrowly separated surfaces.

✍**Static seals**

Between surfaces which do not move relative to each other

✍**Exclusive seals**

Restrict access of dirt, etc., to a system, often used in conjunction with dynamic seals

Rubber seals

Symptoms	Cause	Remedy
- rubber brittle - possibly cracked - seal leaks	- rubber aging - exposure to the sunlight - overheat due to high fluid temperature or high speed	- renew seal - change rubber compound - improve seal environmental or operating conditions
- rubber softened, possibly swollen	- rubber incompatible with sealed fluid	- change rubber compound or change fluid
seal motion irregular - jerky - vibration	-stick-slip phenomena	- higher or lower speed may avoid problem - Change fluid temperature - change rubber
- seal friction very high on starting	- static friction (time dependent)	- probably inevitable - effect slowed by softer rubber or more viscous fluid
- seal permanently deformed	- permanent set (characteristic of rubbers)	-change rubber compound

O-rings, rectangular rubber rings, U-rings

Symptoms	Cause	Remedy
❑ Fine circumferential cut set back slightly from sliding contact zone ❑ Ring completely ejected from its groove	- Extrusion damage	- Reduce back clearance - Check concentricity of parts - Fitting of back-up ring - Use reinforced seal - Use harder rubber
❑ Wear (not restricted to sliding contact) ❑ Partial or total fracture	- Ring rolling or twisting in groove	- Replace O-ring by rectangular section ring or lobed type Ring

Lip seals

Symptoms	Cause	Remedy
Rotating lip seal - Excessive leakage	- Damaged lip (during assembly)	- Remove cause of damage during assembly
- Lip cracked in places	- Excessive speed - Poor lubrication - Hot environment	- Improve lubrication - Reduce environmental temperature - Consider using alternative rubber compound
Reciprocating lip seal - Excessive wear/high Friction	- Poor lubrication - Seal overloaded	- Replace single seal - Use heavy duty seal - For aqueous fluids leather may be better than rubber

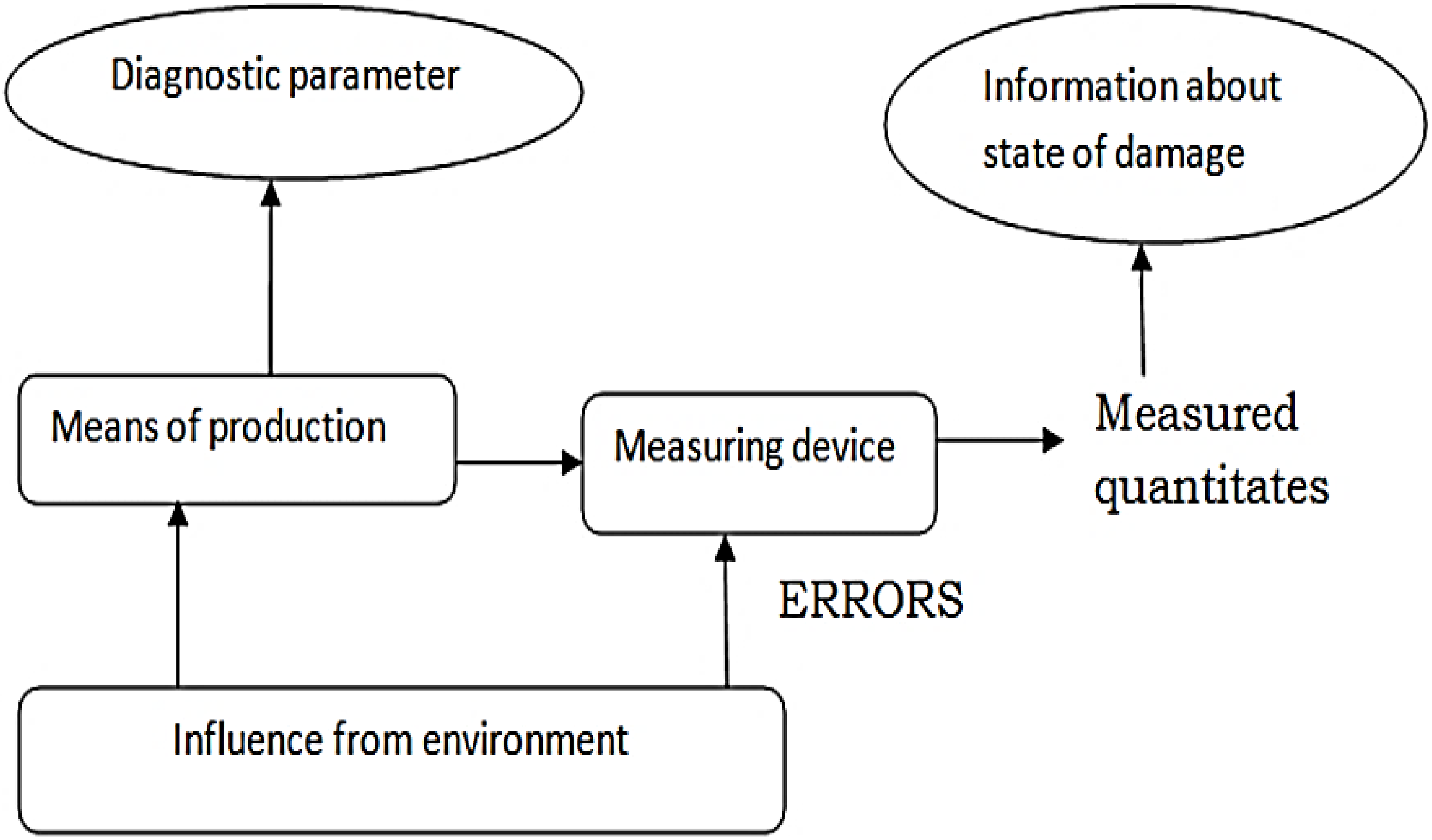
Chapter-4
Determination of state of damage

- The state of damage of machinery is the **undesired deviation** from the required state fixed in the design procedures.
- For the phase of testing of new components or equipment (means of production), knowledge of the state of damage can be used for setting meaningful maintenance routines.
- The state of damage of equipment depends on:-
  - Kind and condition of damage, and
  - Duration of operation of equipment.

Cont.

- Determination of the state of damage is part of technical diagnostics and maintenance.
- Technical diagnostics is the determination of the technical state or state of damage of equipment, evaluation of the state and collection of information for deciding the state and kind of maintenance.
- This is normally done without disassembling while the equipment is in operation.

Cont.



schematic representation of technical diagnostics

Cont.

- Conclusions arrived at about the state of damage of an equipment are probabilistic, and
- The accuracy of results obtained depends on the accuracy of the method of investigation used, sampling techniques.
- Hence, the usefulness of the results has to be weighed carefully and decisions made have to be supported by experienced and good judgment.

4.1 Measuring values for the state of damage

The measuring principles employed are two:

a. Direct measured quantities, and

b. Indirect measured quantities

Direct measured quantities

The direct measuring technique determines the difference between the initial state and the state after wear process.

The measurement taken can be direct linear, volumetric or mass quantities

Cont.

✍These measured quantities can be **absolute or related to duration of operation.**

- **Absolute measurement:-** gives the amount wear as an average worn out thickness.
- **Related measurement:-** gives amount of wear per unit time of operation
- **Direct measurement:-** is usually done after disassembly But it can also be made without disassembling provided there is easy access to the measured quantities.

Indirect measuring quantities

During the operation of a machine or parts of it, certain **signals** are produced which are related to the state of operation of the machine.

These signal, which are known as the **diagnostic parameters;** if properly analyzed provide some information regarding the state of the machine.

It should be noted that influence from the environment introduces errors in the measured results.

4.2 Methods of condition monitoring

Most techniques of condition monitoring amount to the systematic application of commonly accepted methods of fault diagnosis.

These techniques are classified as **on-load or off-load** monitoring techniques.

4.2.1 On-load monitoring techniques

On-load monitoring techniques are mostly carried out without interruption of operation of the unit.

Cont.

These techniques include:

- ☞Visual, aural and tactical inspection of accessible components;
- ☞Temperature monitoring.
- ☞Lubricant monitoring.
- ☞Leak detection.
- ☞Vibration monitoring/sound monitoring and
- ☞Corrosion monitoring.

4.2.3 Off-load monitoring techniques

Off-load monitoring techniques require shutdown of one unit.

These techniques include:

- Crack detection;
- Visual, aural and tactical inspection of normally inaccessible or moving parts;
- Leak detection;
- Vibration testing;
- Corrosion monitoring

4.3. Condition monitoring techniques

Most failures give some warning before they occur. This warning is called potential failure.

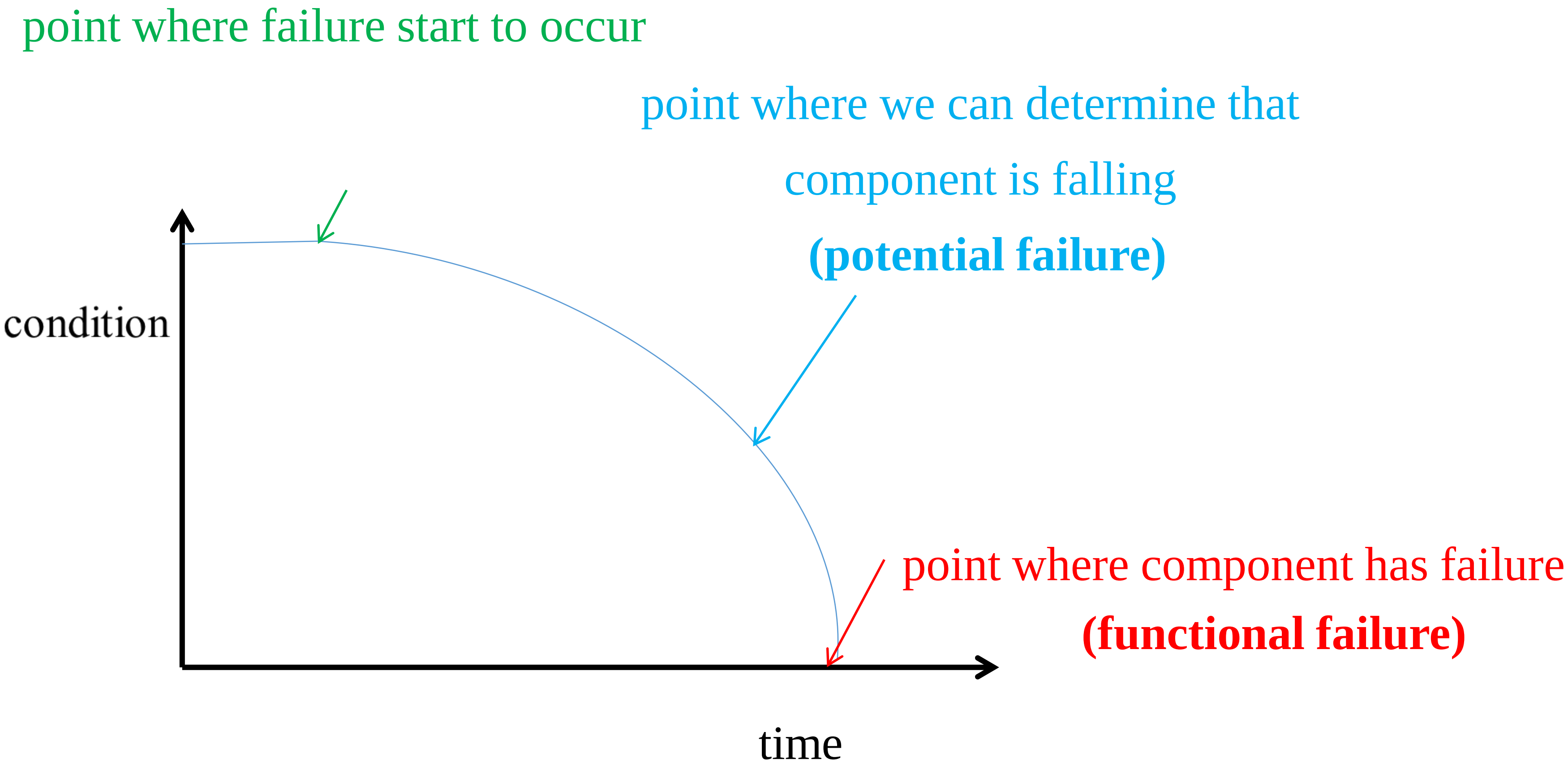
Potential failure is defined as an identifiable physical condition which indicates that a functional failure is either about to **occur** or it is in the **process of occurring;**

A functional failure is defined as the inability of equipment in meeting a specified performance standard.

Potential failures and on-condition maintenance:-

If evidence can be found that some component/equipment is in the final stage of failure, it may be possible to take action to prevent complete failure and/or its consequences.

The P-F curve is employed to show what happens in the final stages of failures:-



The P-F curve shows:-

✓Where failure in the equipment starts to occurs:

✓Where equipment condition going to the point at which the failure can be detected; and finally,

✓Where the equipment has failed indicating functional failure.

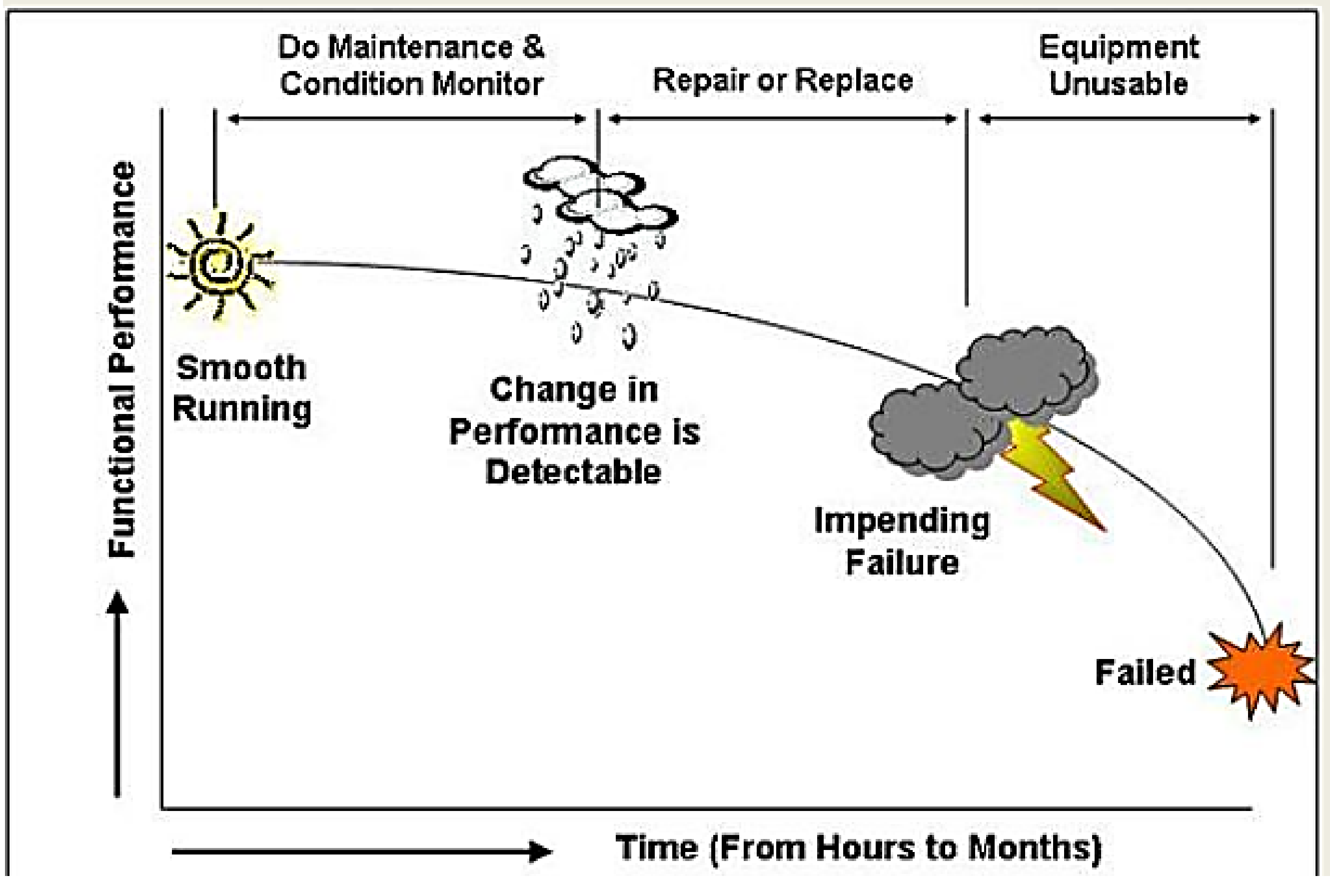


Fig. P-F curve

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The P-F interval:- is the interval between the occurrence of a potential failure and its deterioration in to functional failure. The P-F interval is the warning period, or the lead time to failure, or the failure development period.

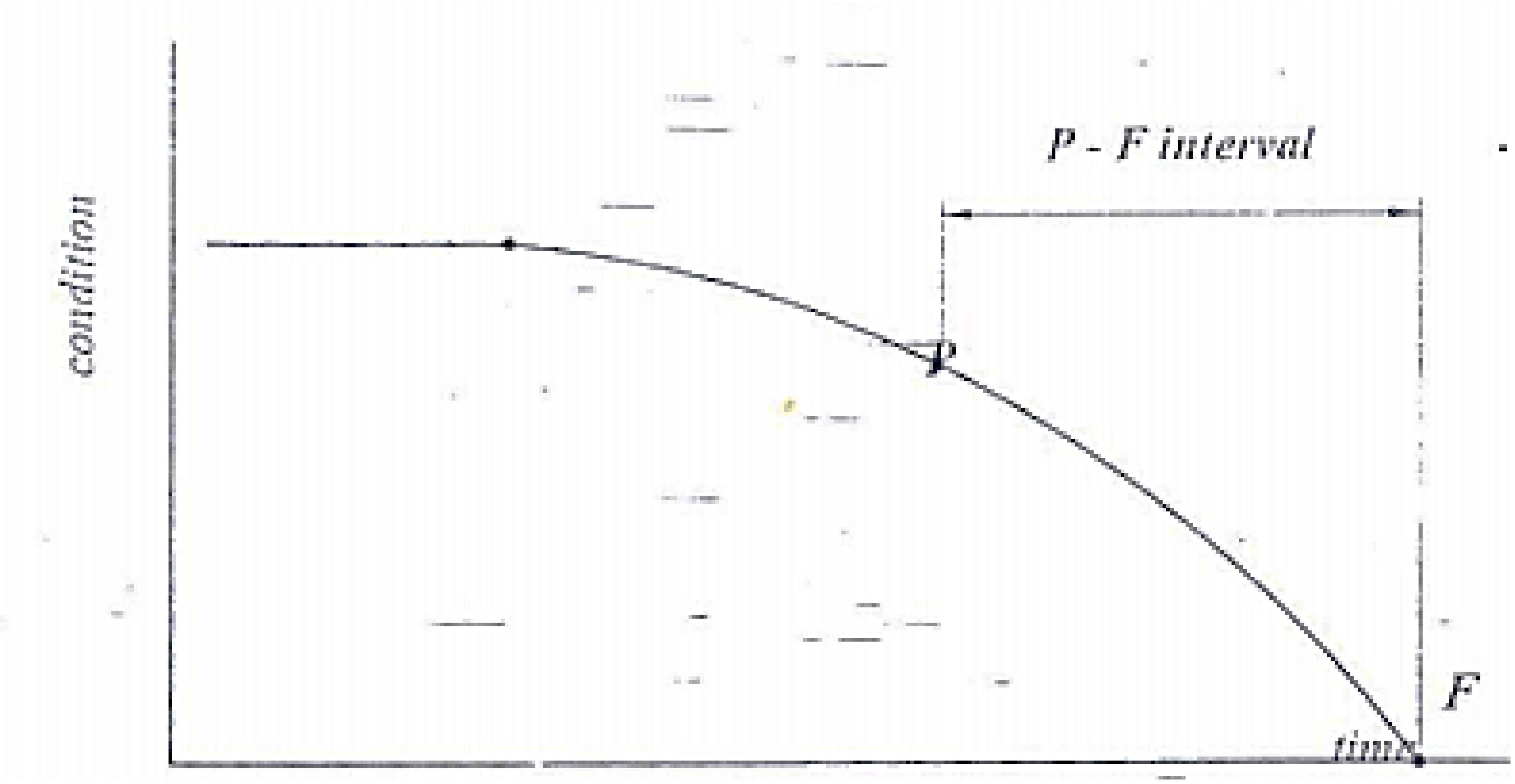


Fig. P-F interval curve

Cont.

- Between points P and F it may be possible to take action to prevent functional failure or to avoid consequences of functional failure.
- Tasks designed to detect potential failures are known as on-condition tasks.
- On - condition tasks entail checking for potential failures so that action can be taken to prevent functional failure or to avoid the consequences of the functional failure. This is known as predictive maintenance or condition-based maintenance.
- The longer the P-F interval for inspection more time to take appropriate actions to avoid the consequence of failure.
- Small deviation from the normal requires sensitive monitoring techniques and equipment.
- It can be concluded that the P-F curve is an important tool-in determining the condition monitoring techniques and setting the equipment for conducting the monitoring task.

4.4. Categories of condition monitoring techniques

Condition monitoring techniques are designed to detect specific symptoms which are related to the state of damage of the equipment.

The monitoring techniques are classified according to the symptoms monitored.

1. Dynamic monitoring

Detects potential failures which cause emissions of abnormal energy in the form of waves such as vibration and noise.

Equipment which contain moving parts that vibrate are monitored dynamically.

Cont.

There are various techniques that belong to this category,

- ✍Broad band vibration analysis (changes in vibration characteristics are monitored by using transducer)
- ✍Constant bandwidth analysis (changes in vibration characteristics are monitored by using accelerometers)
- ✍Real time analysis (measurement of vibrational signals; shock analysis)
- ✍Ultrasonic analysis (changes in sound pattern are monitored)

2. Particle monitoring

Particle monitoring detects potential failures which cause particles of different sizes and shapes to be released in to the environment in which the component is operating. These include wear particles and corrosion particles;

Examples:-

- ★Real time ferromagnetic sensors
- ★Graded filtration
- ★Sedimentation

3. Chemical monitoring

Chemical monitoring detects potential failures which cause traceable quantities of chemical elements to be released in to the environment.

This technique is used to detect elements in the lubricating oil which indicate occurrence of potential failure elsewhere in the system. They are employed to detect wear, corrosion, leakage

- Electro-chemical corrosion monitoring
- Exhaust emission analyzers
- Color indicator titration

4. Physical effect monitoring

Changes in the physical appearance or structure of equipment which can be detected directly. like crack, wear by:-

- ✓Strain gauge
- ✓Viscosity monitoring

5. Electrical effects monitoring

look for changes in resistance, conductivity, etc.

- ✓Electrical resistance monitoring
- ✓Breaker timing testing

6. Temperature monitoring

look for potential failures which cause rise in temperature

- ✓Infrared scanning
- ✓Temperature indicating painting

Chapter 5
Elements of maintenance

Broadly speaking, the elements of maintenance technology can be classified as Attendance (operation), servicing and repair.

5.1. Attendance (Operation)

Attendance is the right way of avoiding **mal - operation** which influences the damages and indirectly the maintenance.

Cont.

The fundamentals for the use of any technical means of production are:

- Proper use of **operating instruction** provided in operators manuals;
- Proper use of **service instructions** given in service instructions; and
- Following proper **maintenance procedures** and **instructions** as outlined in maintenance manuals.

Cont.

- Knowledge of these instructions is essential in attending the machine.
- In this respect qualification of operators, maintenance personnel and management is a requirement.
- **Proper attendance avoids subjective damages** (due to mis-handling) and minimizes objective damages.

5.2. service

Servicing of a machine is important in decelerating wear or damage of machine parts. Important measures to be taken in servicing are:-

A. cleaning,
B. Lubricating and
C. Adjusting.

5.2.1. cleaning

☞Penetration of dust, dirt deposited, etc. accelerate the wear processes and corrosion of machine components.

☞**Hence cleaning makes the preliminary maintenance element.**

☞Cleaning should be done in short time intervals and

☞The means used for cleaning should not be corrosive and should not damage paints, working surfaces, etc.

Cont.

- ☞For cleaning purposes detergents can be used, but **compatibility** with the working environment should be given due attention.
- ☞Accessories like water jet, steam jet or compressed air can be used to assist cleaning of machinery.

5.2.2 lubricating

A lubricant has the task of:-

- ✓reducing friction between mating surfaces with relative motion,
- ✓transfer of heat generated and
- ✓prevention of dust and other materials from entering in to the working environment.

Rules for lubricating include:-

- ❑Use the right lubricant and the specified amount
- ❑Complete replacement of lubricant

Cont.

- Avoiding contaminants at the point of lubrication
- In applying lubricants, taking good care of filters is of great importance.
- The task of filters is to separate wear products and contaminants from the lubricant to reduce wear process.
- Different types of oil filters, air filters, restrainers can be used.

5.3. Repairs

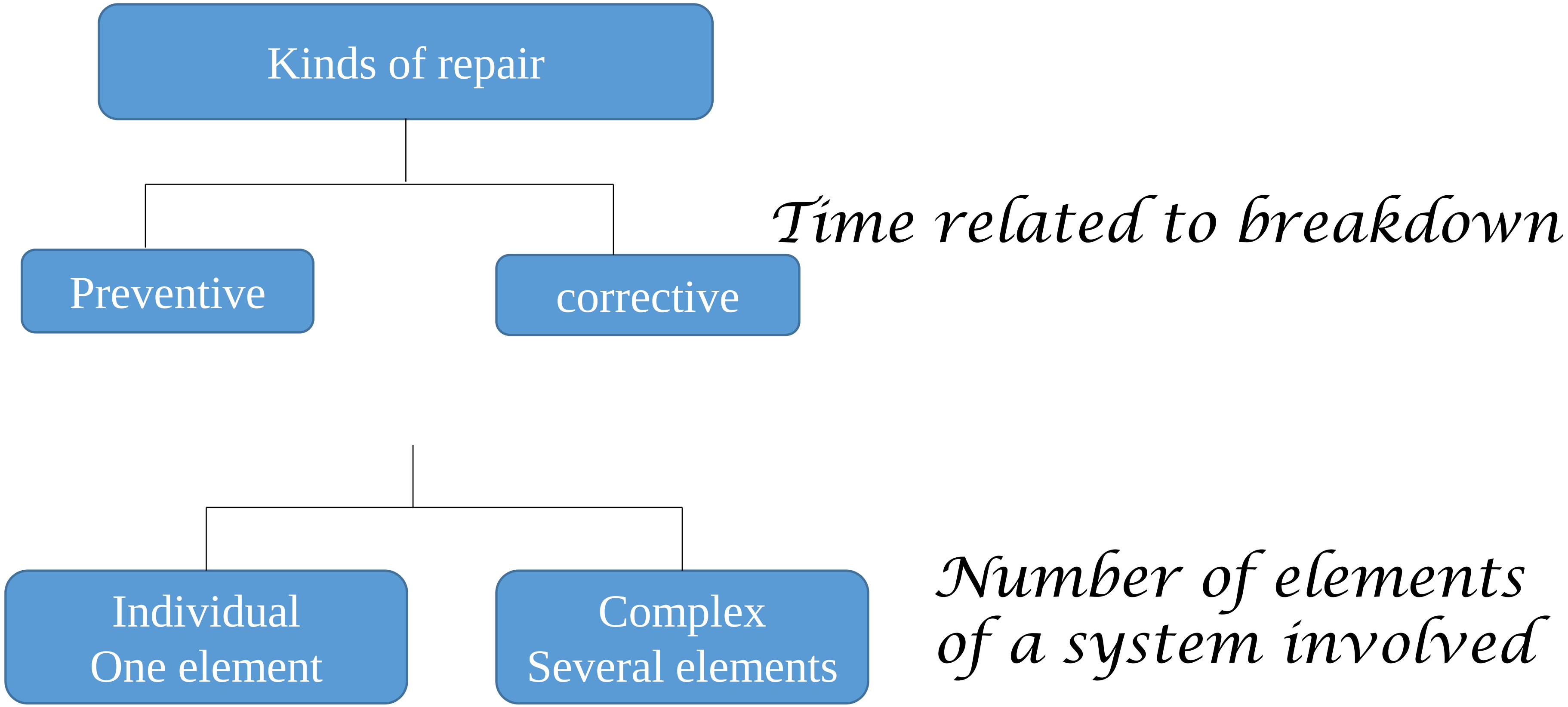
Repair is the totality of measures of restoration with the aim of determined final state, or quality, or condition of equipment.

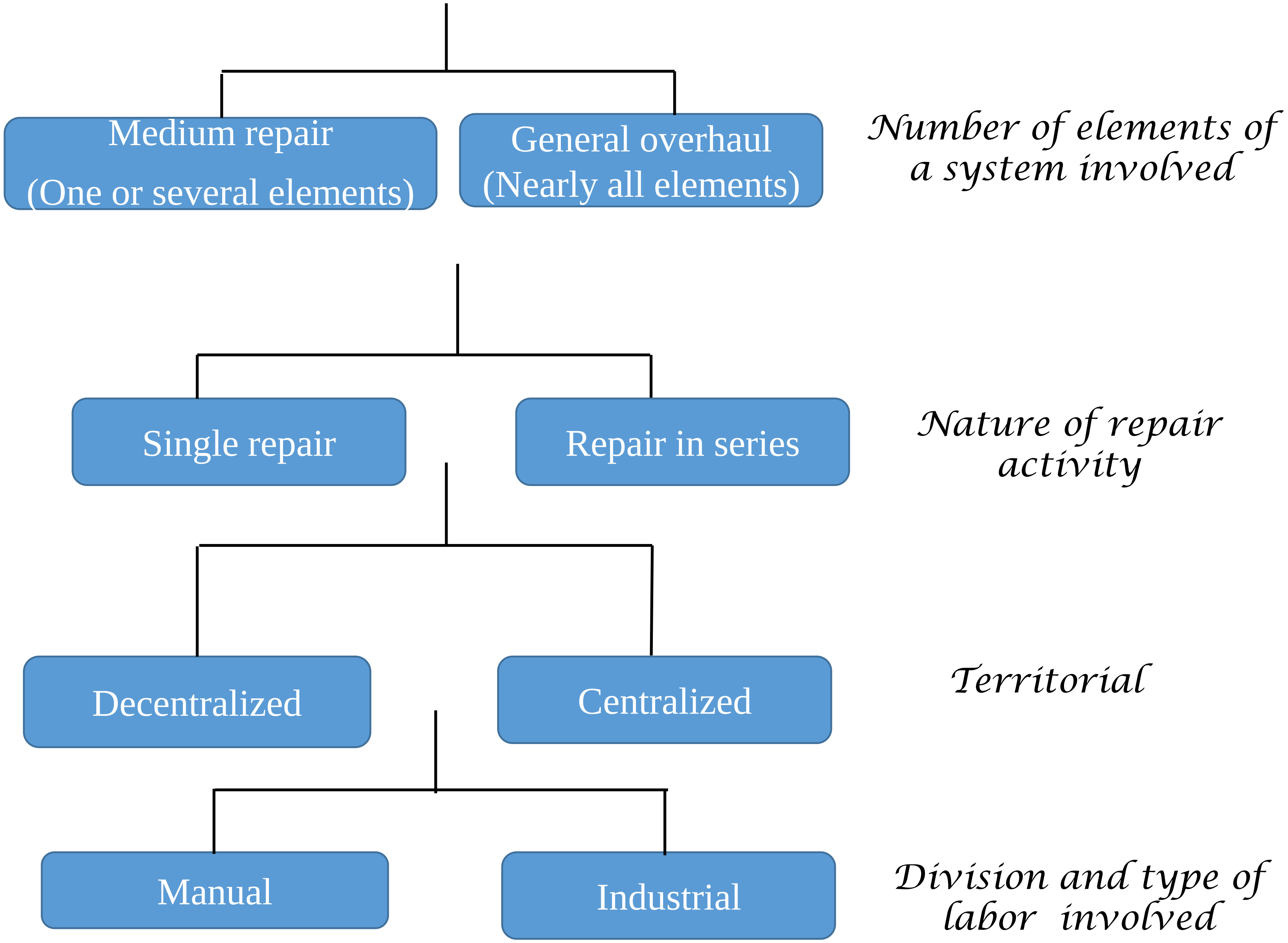
Classification of repair activities is based on various consideration.

These considerations are:-

- ✍Time related breakdown
- ✍Number of elements involved in the repair task
- ✍Nature of repair activity
- ✍Territorial, or
- ✍Labor involved

The classification of repair activities are outlined in the chart below:-




Medium repair
(One or several elements)
General overhaul
(Nearly all elements)
Number of elements of a system involved
Single repair
Repair in series
Nature of repair activity
Decentralized
Centralized
Territorial
Manual
Industrial
Division and type of labor involved

Chapter 6
Maintenance strategies and decision making

Maintenance is the combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required.

Almost every business/industry has some sort of maintenance program for its physical assets. As such, over period of time, **many maintenance strategies or methodologies have been developed mainly basing on:-**

- Time for doing maintenance,
- Frequency of maintenance,
- Quality of maintenance,
- Complexity , and sophistication of equipment's and
- Value of total assets etc.

Basis of selecting maintenance strategies

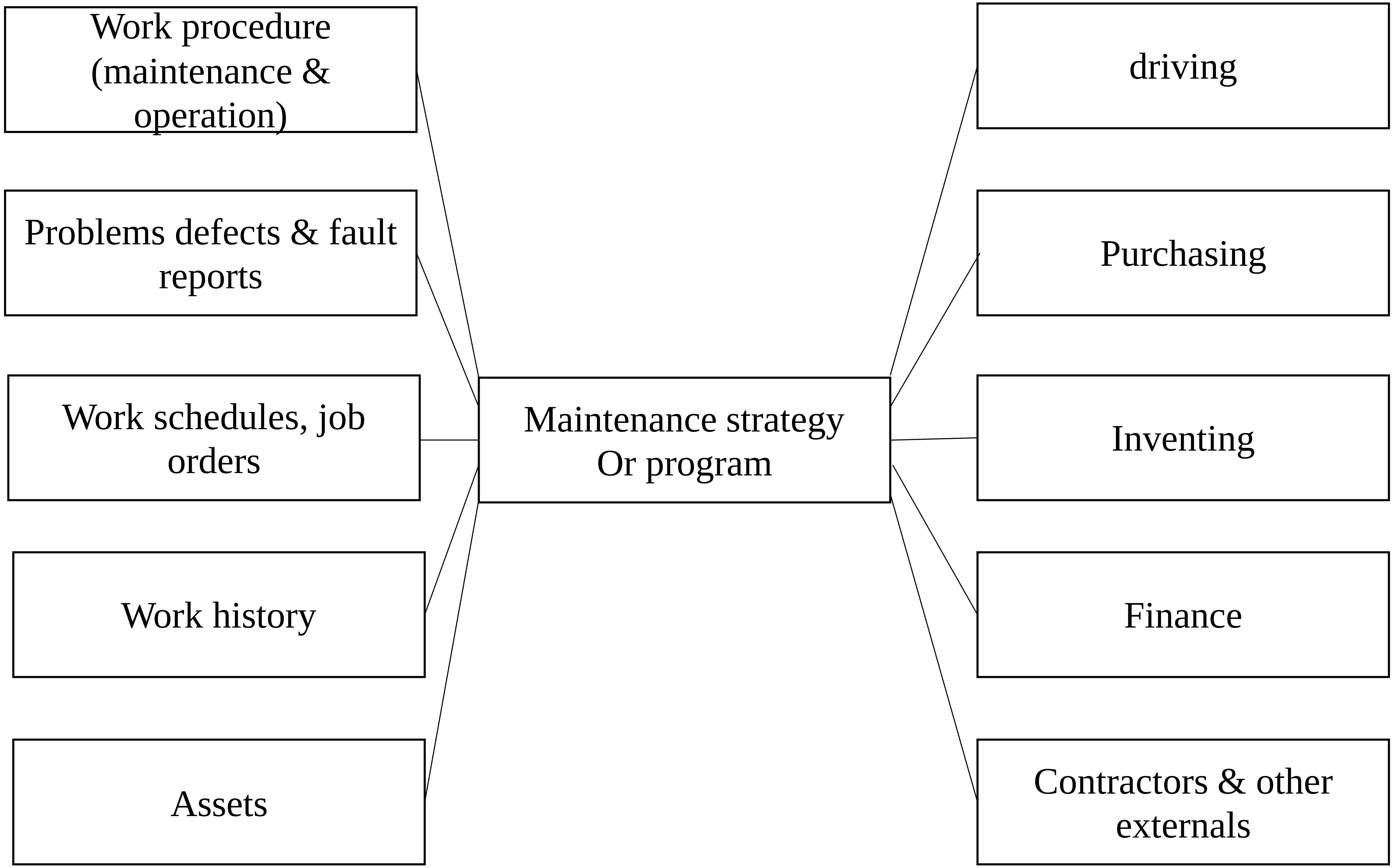
- ❑ Maintenance strategies are methodologies and software programs which balance maintenance costs against the impact of plant failure.
  - Too little of maintenance can cause costly system failures
  - Too much of maintenance is not cost-effective
- ❑ By optimizing equipment maintenance strategies against both targets, availability and the penalty of failure, you can optimize your asset life-cycle costs.

There are various reasons for selecting maintenance strategies such as: -

- Which set of tasks that should be performed and their frequency,
- With aging of the plant a different mix of tasks is needed to maintain reliability,
- Perhaps with reduced staff it is not possible to perform all tasks that used to be done and, only the most effective tasks are selected, or
- The plant operators may want to reduce maintenance expenditures without elevating risk or reducing reliability;
- The resulting strategy must strike a balance between maintenance cost and plant reliability.

.....cont’d

- This evaluation **develops tools and techniques for determining the best mix of maintenance tasks.**
- An element of the maintenance strategy is to prioritizing maintenance tasks.
- One approach is called risk-based evaluation and prioritizing (REAP).
- REAP has been successfully used to prioritize routine and outage maintenance tasks, based on improved reliability and cost of the task.
- Any good maintenance strategy must have an integrated information system for interacting with all concerned areas such as shown below



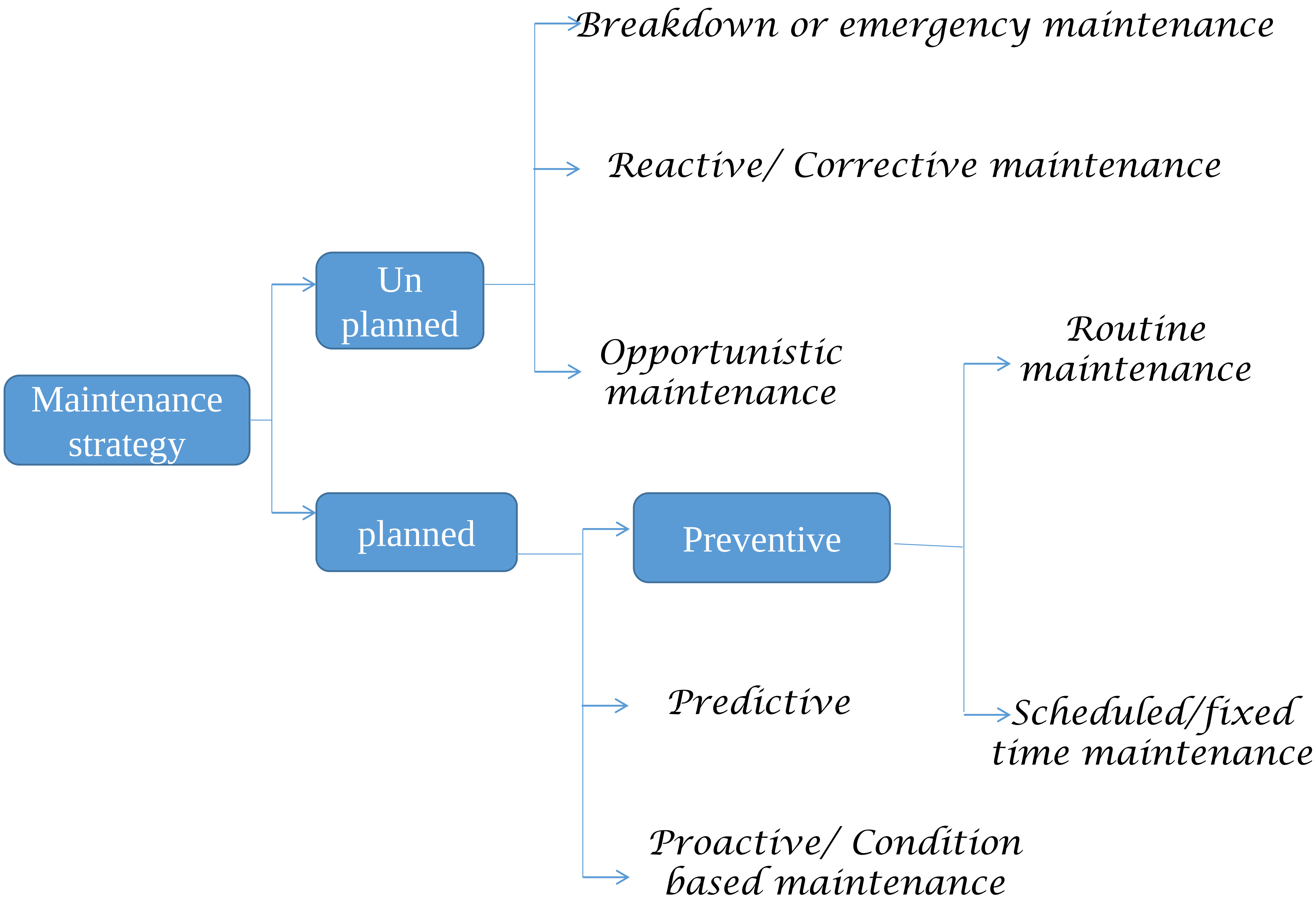
Integrated information systems for maintenance strategy

Selection criteria and types of maintenance

Selection of maintenance systems/strategies has to be made depending on:-

- The need,
- Complexity,
- Reliability needed and
- Considering techno- economics

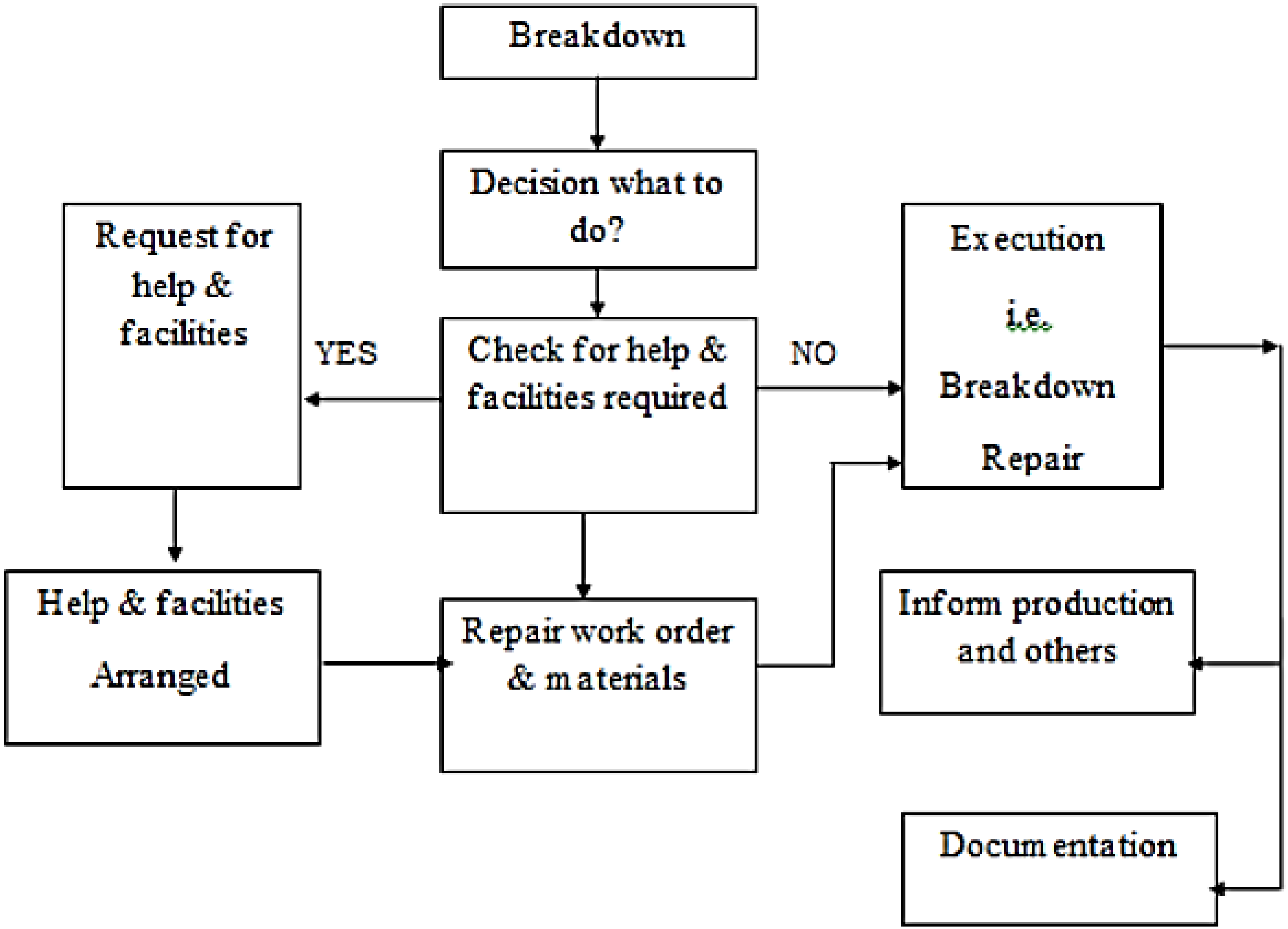
Most of the commonly used strategies can be grouped as shown:-


Maintenance strategy
Un planned
planned
Breakdown or emergency maintenance
Reactive/ Corrective maintenance
Opportunistic maintenance
Preventive
Predictive
Proactive/ Condition based maintenance
Routine maintenance
Scheduled/fixed time maintenance

1. Breakdown or emergency maintenance

- ☞In such maintenance, repair is done after failure has already occurred
- ☞Only when the equipment fails to perform designated functions or comes to a grinding halt, any maintenance or repair job is taken.
- ☞It may work well in a small factory/plant, where, Number of equipment are few,
- ☞Equipment are simple and repair does not call for specialists or special tools/tackles,
- ☞When sudden stoppage/ failure of the equipment will not cause severe finical loss in terms of delivery commitment or further damage to other equipment/components,
- ☞When sudden failure will not cause any severe safety or environmental hazards.

☞ However, such maintenance system cannot work in big industries, having large number or equipment, some of which may be quite intricate.



2. Corrective maintenance

- Corrective maintenance means action for correcting or restoring a failed unit (or unit going to fail). Its scope is very vast and may include different types of actions, from small actions like typical adjustments and minor repairs to minor redesign of equipment.
- It is mostly unplanned action, but may include few planned/ scheduled actions.

Actions in corrective maintenance may be subdivided, according to priority, as follows:-

- Emergency work, high priority, generally offline, i.e. after stopping the equipment. Giving normally less than 24 hours notice to take up the job,
- Deferred works-jobs of lower order priority; generally off-line, to eliminate / reduce repetitive break downs, and
- Specific reconditioning or redesign jobs, generally small or medium in volumes.

WHAT ABOUT

- ☞ *Opportunistic maintenance?*
- ☞ *Routine maintenance?*
- ☞ *Scheduled/fixed time maintenance?*
- ☞ *Predictive Maintenance?*
- ☞ *Proactive/ Condition based maintenance?*

YOUR READING ASSIGNMENT

Maintenance Decision-making Process

The decision-making procedure allows the selection of an optimum set of maintenance procedures.

Maintenance decision making can be broadly explained in terms of maintenance actions, (basic elementary work), maintenance policies and maintenance concepts.

Three maintenance decisions according to the questions of when, which, and what is needed. The question of:-

- ‘when’ refers to the right time to perform a maintenance;
- ‘which’ refers to the selection of the right component in the multi-component structure that requires maintenance; and
- ‘what’ refers to the appropriate maintenance action (e.g., repair or replace) to be carried out.

Chapter 7
Basic Probability Concepts

Introduction

People use the term probability many times each day. For example, physician says that a patient has a 50-50 chance of surviving a certain operation. Another technicians may say that the machine is 95% certain that a machine has a particular failure.

Definition

- If an event can occur in N mutually exclusive and equally likely ways, and if m of these possess a trait, probability of the occurrence of E is read as:-

$$P(E) = m/N$$

Definition

Experiment = any planned process of data collection. It consists of a number of trials (replications) under the same condition.

- **Sample space:** collection of unique, non-overlapping possible outcomes of a random circumstance.
- **Simple event:** one outcome in the sample space; a possible outcome of a random circumstance.
- **Event:** a collection of one or more simple events in the sample space; often written as A, B, C, and so on.

$$\{A, B\}$$

Cont.

Complement = sometimes, we want to know the probability that an event will not happen; an event opposite to the event of interest is called a complementary event.

If A is an event, its complement is The probability of the complement is AC or $\bar{A}$

Example: The complement of male event is the female.

$$P(\text{A}) + P(\text{AC}) = 1$$

Views of Probability:

1-Subjective:

It is an estimate that reflects a person's opinion, or best guess about whether an outcome will occur.

Important in garage ➔ form the basis of a technician opinion (based on information gained in the history and technicians examination) about whether a vehicle or machine has a specific problem.

Such estimate can be changed with the results of diagnostic procedures.

2- Objective

A. Classical

- It is well known that the probability of flipping a fair coin and getting a “tail” is 0.50.
- If a coin is flipped 10 times, is there a guarantee, that exactly 5 tails will be observed
- As the number of flips becomes larger, the proportion of coin flips that result in tails approaches 0.50

Example: Probability of lathe versus milling imported

Long-run relative frequency of lathe is about 0.512 **(512) lathes imported per 1000 total lathe and milling import)**

Table provides results of simulation: the proportion is far from .512 over the first few weeks but in the *long run* settles down around .512.

Weeks of watching	Total imported machines	Total lathes	proportion
1	30	19	.633
4	116	68	.586
13	317	172	.543
26	623	383	.615
39	919	483	.526
52	1237	639	.517

Cont.

B) Relative frequency

Assuming that an experiment can be repeated many times and assuming that there are one or more outcomes that can result from each repetition. Then, the probability of a given outcome is the number of times that outcome occurs divided by the total number of repetitions.

Problem 1.

Vehicle Group	Problem of Engine	Problem of Clutch	Total
Truck Automobile Bus Roller	20 17 8 5	20 18 7 5	40 35 15 10
Total	50	50	100

Problem 2.

An outbreak of not functional occurs in a group of machines who attended in maintenance shop

	Not functional	functional	Total
lubricated	90	30	120
Did Not lubricated	20	60	80
Total	110	90	200

a. Marginal probabilities

Named so because they appear on the "margins" of a probability table. It is probability of single outcome.

Example: In problem 1, P(engine), P(vehicle group truck)

P(engine) = number of engine/total number of subjects/problem

= 50/100

= 0.5

b. Conditional probabilities

It is the probability of an event on condition that certain criteria is satisfied.

Example: If a subject was selected randomly and found to be **clutch** problem what is the probability existed on the **Truck**

Here the total possible outcomes constitute a subset (clutch) of the total number of subjects.

This probability is termed probability of Truck given C

P(problem on Truck\ caused by Clutch error) = 20/50

= 0.40

c. Joint probability

It is the probability of occurrence of two or more events together.

Example: Probability of problem of being **Engine** & **belong to Roller**

$P(E \text{ and } R) = P(E \cap R)$

$= P(E) X P(R) = (50/100) X (10/100)$

$\underline{= 0.05}$

$\cap$ = intersection

Properties

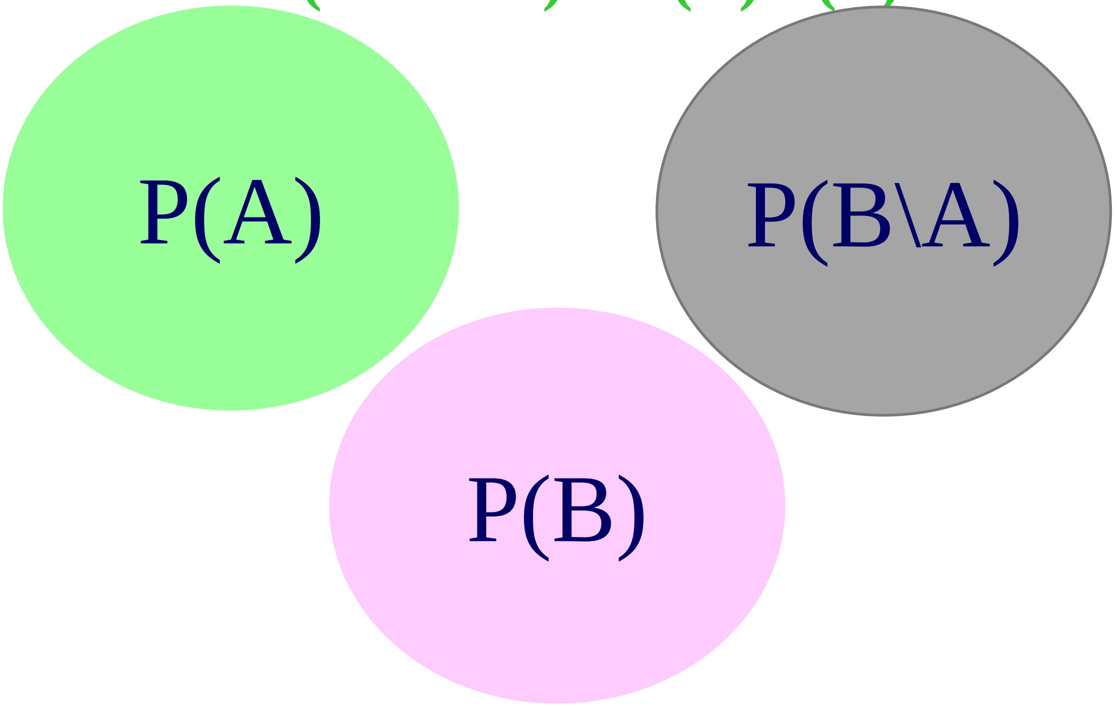
- The probability ranges between 0 and 1
- If an outcome cannot occur, its probability is 0
- If an outcome is sure, it has a probability of 1
- The sum of probabilities of mutually exclusive outcomes is equal to 1 $P(E) + P(C) = 1$

Rules of probability

1- Multiplication rule

Independence and multiplication rule

P(A and B) = P(A) P(B)



A and B are independent

P(B\A) = P(B)

Example:

The joint probability problem of an Engine and having in truck

To know that two events are **independent compute the marginal and conditional probabilities of one of them if they are equal the two events are independent. If not equal the two events are dependent**

$P(truck) = 40/100 \quad = 0.40$

$P(T \backslash E) = 20/50 \quad = 0.40$

Then the two events are independent

$P(T \cap E) = P(T) \times P(E) = (40/100) \times (50/100)$ **= 0.20**

Cont.

1- Multiplication rule

Dependence and the modified multiplication rule

P(A and B) = P(A) P(B\A)

P(A) **P(B\A)**

P(B) **P(B\A)**

A and B are not independent

$P(B \backslash A) \neq P(B)$

Example:

The joint probability of * not functional and applied lubricant*

P(not functional) = 110/200 = 0.55

P(not functional\applied lubricant) = 90/120 = 0.75

- **Then the two events are dependent**

P(not functional ∩ applied lubricant)

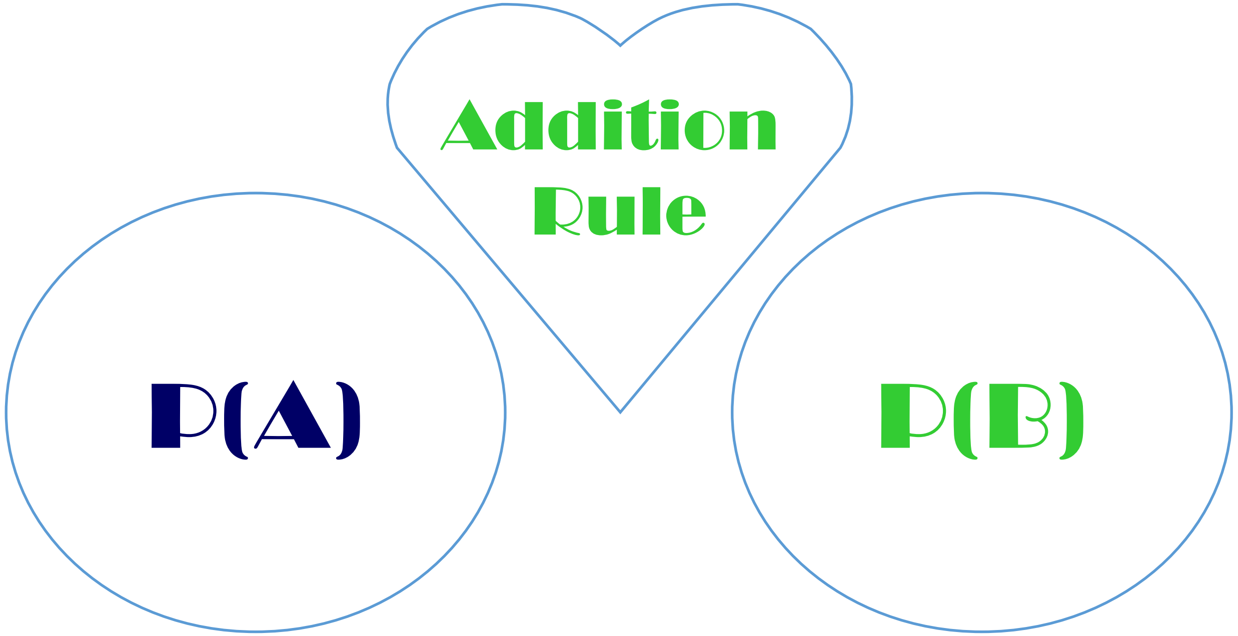
= P(applied lubricant)×P(not functional \ P(applied lubricant)

= (120/200)×(90/120)

= 0.45

2- Addition rule

i) A and B are mutually exclusive, The occurrence of one event precludes the occurrence of the other



P(A OR B) = P(A U B) = P(A) + P(B)

Example:

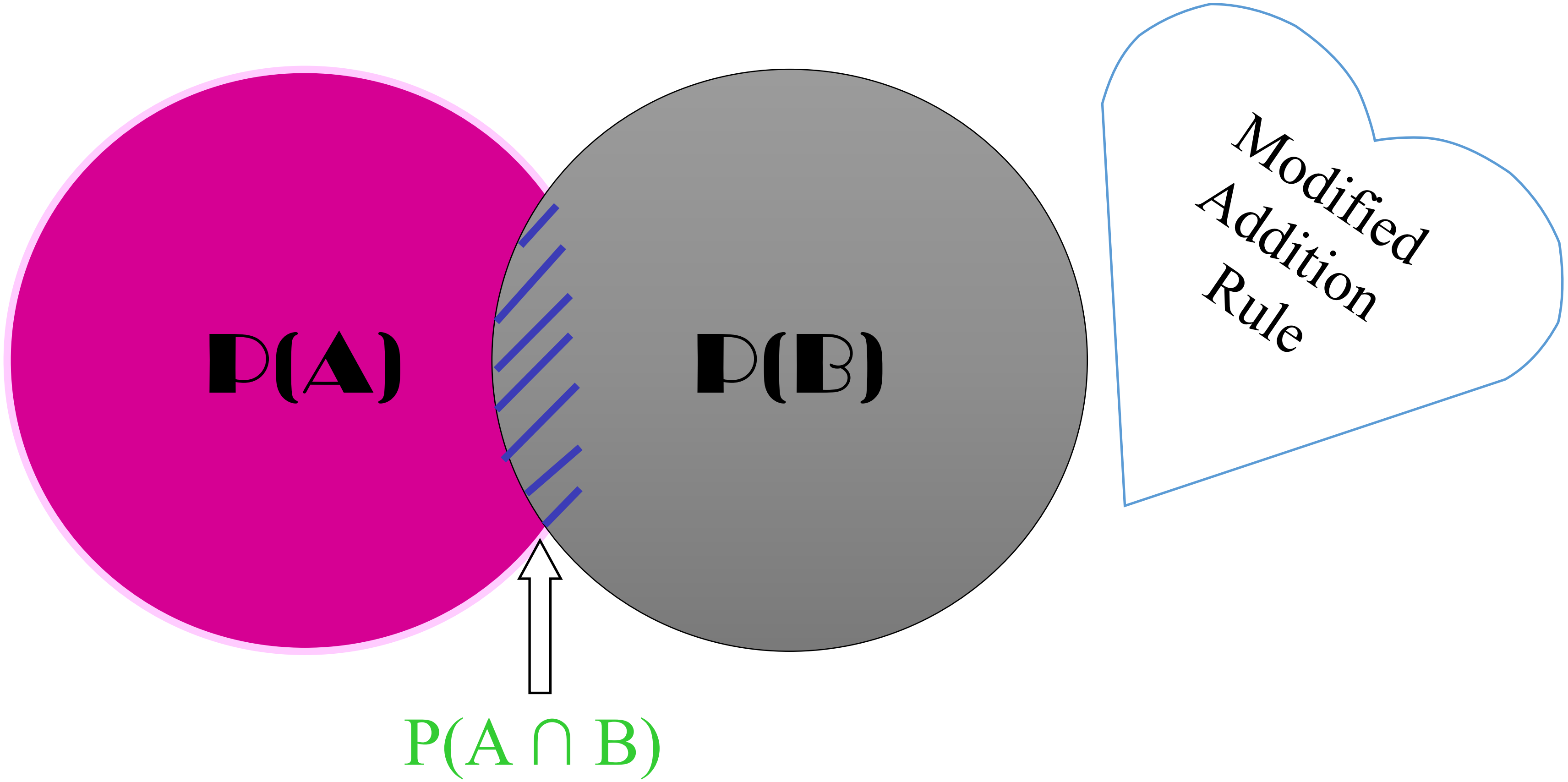
The probability of being either Truck or Automobile

$$P(OUA) = P(T) + P(A)$$

$$= (40/100)+(35/100)$$

$$\underline{= 0.75}$$

ii) A and B are non mutually exclusive (Can occur together)
Example: Male and smoker



$$P(A \text{ OR } B) = P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

Example:

Two events are not mutually exclusive (engine problem and truck type vehicle).

P(E OR T) = P(Engine)+P(Truck) – P(Engine ∩ Truck)

= 0.50 + 0.40 – 0.20

= 0.70

Chapter 8

Reliability, Maintainability, Availability and capability

Availability, reliability, maintainability and **capability** are components of the effectiveness equation is a figure of merit which is helpful for deciding which component detract from performance measures. In many continuous process plants the reliability component is the largest detractor from better performance.

Each effectiveness element varies as a probability. Since components of the effectiveness equation and its forms, it varies from one writer to the next.

$$System\ effectiveness = effectiveness/LCC$$

Where :- LCC – Life cycle cost

effectiveness = availability*reliability*maintainability*capability

The effectiveness equation is the product of:-

- ✓The chance the equipment or system will be available to perform its duty
- ✓It will operate for a given time without failure,
- ✓It is required without excessive lost maintenance time and
- ✓It can perform its intended production activity according to the standard.

Each element of the effectiveness equation requires a firm datum which changes with name plate ratings for a true value that lies between 0 and 1.

Reliability Definition

- Generally defined as the **ability of a product to perform, as expected, over certain time.**
- Formally defined as the **probability** that an item, a product, piece of equipment, or system will **perform** its intended function for a **stated period of time** under specified **operating conditions.**
- In the simplest sense, **reliability means how long an item (such as a machine) will perform its intended function without a breakdown.**

Reliability is performance over time, probability that something will work when you want it to.

The Reliability definition has four important elements:-

Probability (A value between 0 and 1, number of times that an event occurs (success) divided by total number trials)

e.g. probability of 0.91 means that 91 of 100 items will still be working at stated time under stated conditions

Performance (Some criteria to define when and how product fails, which also describes what is considered to be satisfactory system operation)

e.g. amount of beam collisions, etc.

Time (system working until time (t), used to predict probability of an item surviving without failure for a designated period of time)

Operating conditions

These describe the operating conditions (environmental factors, humidity, vibration, shock, temperature cycle, operational profile, etc.) that correspond to the stated product life.

Basic Reliability Terms

Failure - A failure is an event when an item is not available to perform its function at specified conditions when scheduled or is not capable of performing functions to specification.

Failure Rate - The number of failures per unit of gross operating period in terms of time, events, cycles.

MTBF - Mean Time Between Failures - The average time between failure occurrences. The number of items and their operating time divided by the total number of failures. For Repairable Items

MTTF - Mean Time To Failure - The average time to failure occurrence. The number of items and their operating time divided by the total number of failures. For Repairable Items and Non-repairable Items

Hazard - The potential to cause harm. Harm including ill health and injury, damage to property, plant, products or the environment, production losses or increased liabilities.

Risk - The likelihood that a specified undesired event will occur due to the realisation of a hazard by, or during work activities or by the products and services created by work activities.

Cont.

Maintainability - A characteristic of design, installation and operation, usually expressed as the probability that an item can be retained in, or restored to, specified operable condition within a specified interval of time when maintenance is performed in accordance with prescribed procedures.

MTTR - Mean Time To Repair - The average time to restore the item to specified conditions.

Maintenance Load - The repair time per operating time for an item.

Availability - A measure of the time that a system is actually operating versus the time that the system was planned to operate. It is the probability that the system is operational at any random time t.

Supportability - The ability of a service supplier to maintain the Plant inbuilt reliability and to perform scheduled and unscheduled maintenance according to the Plant inbuilt maintainability with minimum costs.

cont.

As Reliability Engineering is concerned with **analyzing failures** and **providing feedback to design and production** to **prevent future failures,** it is only natural that a rigorous classification of failure types must be agreed upon.

Reliability engineers usually speaks of:-

Failures Causes

Failure Modes

Failure Mechanisms

*A **failure** is an event at which the system stops to fulfill its specified function.*

Reliability measurement is based on the failure rate

$$\text{Failure rate} = \frac{\text{Items Failed}}{\text{Total Operating Time}}$$

- Some products (Non-repairable) are scrapped when they fail e.g. bulb
- Other products (Repairable) are repaired e.g. washing machine.

How Do Products Really Fail?

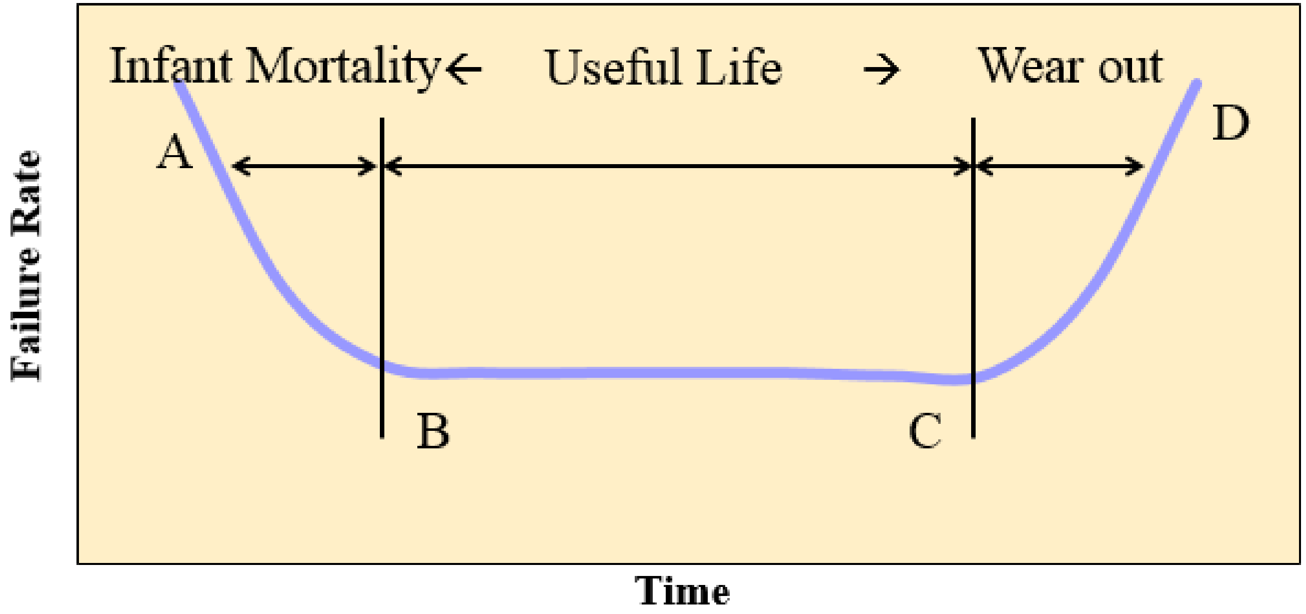
Two common types of failures:

1. Sudden failure (no indicators): Stress exceeds strength ….
2. Degradation (gradual wear out): degradation indicator such as crack growth, change of resistance, corrosion, … This is ideal for Condition-Based Maintenance

Other failures may occur because of human errors.

Failure rate over the life of a product

*The failure rate is expected to vary over the life of a product – **'Bathtub Curve'***



Bathtub Curve.

A-B Early Failure / Infant mortality / Debugging / Break-in

- 'Teething' problems. Caused by design/material flaws

  Eg: Joints, Welds, Contamination, Misuse, Miss - assembly

B-C Constant Failure / Useful life.

- Lower than initial failure rate and more or less constant until end of life

C-D End of life failure / Wear out phase.

- Failure rate rises again due to components reaching end of life

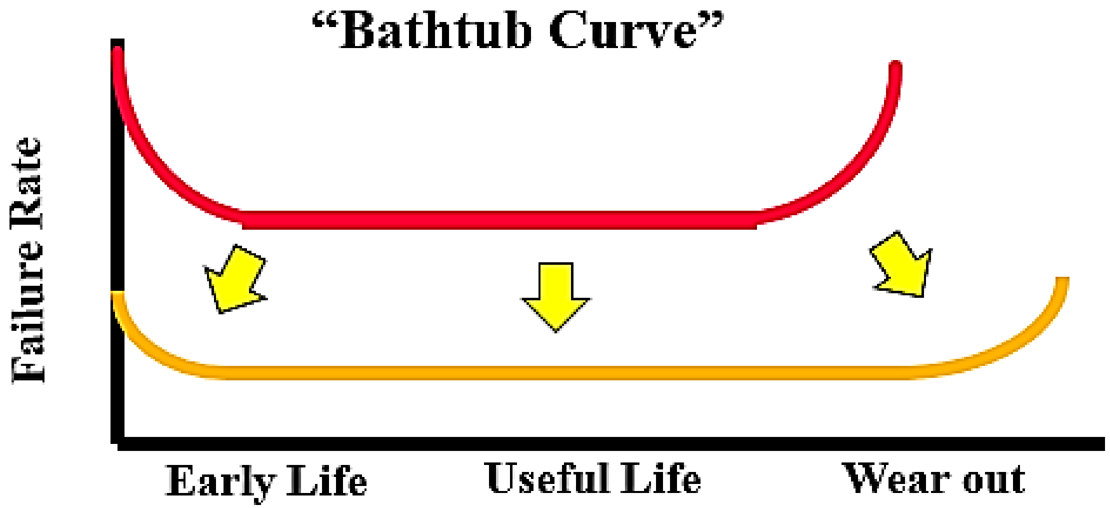
  E.g.:- Corrosion, Cracking, Wear, Friction, Fatigue, Erosion, Lack of PM

Bathtub Curve: Summary Table

Phase	Failure Rate	Possible Causes	Possible improvement actions.
Burn-in (A-B)	Decreasing (DFR)	Manufacturing defects, welding, soldering, assembly errors, part defects, poor QC, poor workmanship, etc	Better QC, Acceptance testing, Burn-in testing, screening, Highly Accelerated Stress Screening, etc.
Useful Life (B-C)	Constant (CFR)	Environment, random loads, Human errors, chance events, 'Acts of God', etc	Excess Strength, redundancy, robust design, etc
Wear-out (C-D)	Increasing (IFR)	Fatigue, Corrosion, Aging, Friction, etc.	Derating, preventive maintenance, parts replacement, better material, improved designs, technology, etc.

Managing Reliability

- Reliability management is **concerned with performance** and **conformance** over the **expected life of the product**
- A systems approach to planning for, designing in, verifying, and tracking the reliability of products throughout their life to achieve reliability goals.
- Reliability of a system is often **specified by the failure rate λ.**
- λ = failures per time unit (in a collection of systems)
- For most technical products (incl. embedded systems), λ(t) is a “bath-tub curve“:



Reliability Characteristics

Non-Repairable Systems:

- ✓Reliability=Availability
- ✓Failure Rate
- ✓MTTF
- ✓Time to First Failure
- ✓MRL (Mean Residual or remaining Life)

Repairable Systems:

- ➢Availability …. (Function of Reliability and Maintainability)
- ➢Failure Rate and Repair Rate
- ➢MTBF
- ➢MRL (Economic Justification)

Failure Rate for Repairable and Non-repairable systems

MTBF θ = *Total time / Total Number of failures*

Average Failure Rate $\lambda = 1/\theta \rightarrow \lambda\,\theta = 1$

Example:

1) 300 cars have accumulated 45000 hours, 10 failures are observed. What is the MTBF? What is the failure rate?

Note: considering Car as repairable system, Use MTBF

MTBF = 45000/10 **= 4500 hours.**

Average Failure rate λ = 10/45000 = **0.00022 per hour.**

2) Five oil pumps were tested with failure hours of 45, 33, 62, 94 and 105. What is the MTTF and failure rate?

Note:- considering pumps as non repairable systems, Use MTTF.

MTTF = (45+33+62+94+105) / 5 = **67.8 hours**

Failure rate λ= 5 / (45+33+62+94+105) = **0.0147 per hour.**

Note that MTTF is a reciprocal of failure rate.

Example

10 components were tested. The components (not repairable) failed as follows:-

Component 1,2,3,4,5 failed after 75,125, 130, 325, 525 hours. Find the failure rate and mean time till failure.

Solution:-

No. of failures = **5**

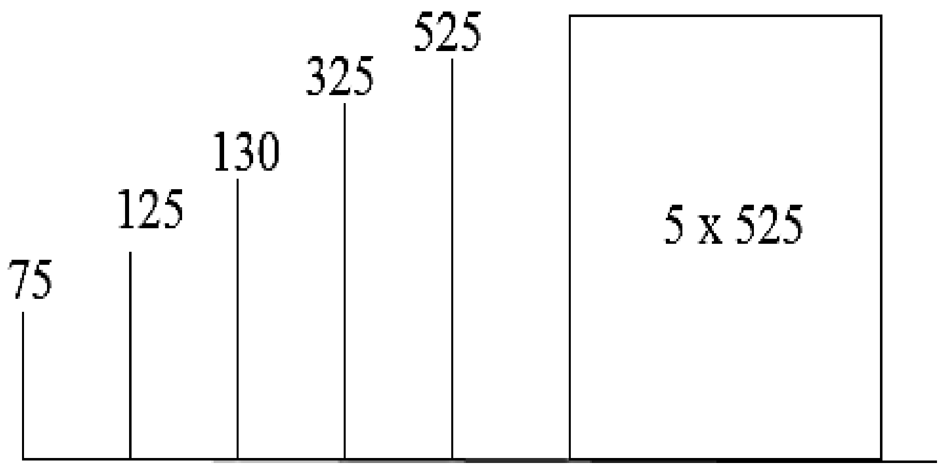
Total operating time = 75 + 125 + 130 + 325 + 525 + 5*525 = **3805**

Failure rate λ = 5 / 3805 = **0.001314**

Mean time till failure = $1/\lambda$

=1/0.001314

= 761.04 hours.



Example:

50 components are tested for two weeks. 20 of them fail in this time, with an average failure time of 1.2 weeks. **What is the mean time till failure assuming a constant failure rate?**

Answer:

No. Of failures = 20

Total time = 20*1.2 + 30*2 = 84 weeks

Failure rate = 20/84 = 0.238/week

Mean time till failure is estimated to be = (1/failure rate)

= 1/0.238 = 4.2 weeks.

Example

The chart below shows operating time and breakdown time of a machine.

a) Determine the MTBF.

Solution:

Total operating time = 20.2 + 6.1 + 24.4 + 4.2 + 35.3 + 46.7

= 136.9 hours

Cont.

$\lambda = 4 / 136.9 = 0.02922$

Therefore;

θ= ***MTBF = 1***/ λ = *34.22 hours*

b) What is the system reliability for a mission time of 20 hours?

$\mathcal{R} = e^{-\lambda t}$ $t = 20$ *hours*

$R = e^{-(0.02922)(20)}$

R = 55.74%

Maintainability

- ***Maintainability*** is the measure of the ability of a system or item to be retained or restored to a specified condition when maintenance is performed by qualified personnel using specified procedure and resources.
- ***Maintabnility*** can be measured with Mean Time To Repair *(MTTR)*, MTTR is average repair time and is given by
- ***MTBMA*** *is Mean Time Between Maintenance Actions including preventive and corrective maintenance tasks.*

$$MTTR = \frac{Total\ Ma\operatorname{int}enance\ Down\ Time}{Total\ Number\ of\ Ma\operatorname{int}enance\ Actions.}$$

OBJECTIVES OF MAINTAINABILITY

- To influence design to achieve case of maintenance thus reducing maintenance time & cost.
- To estimate the downtime for maintenance which, when compared with allowable downtime, determines whether redundancy is required.
- To estimate system availability by combining maintainability data with reliability data.
- To estimate the man-hours and other resources required for performing maintenance, which are useful for determining the costs of maintenance and for maintenance planning.

ADVANTAGES OF MAINTAINABILITY PREDICTION

1. It highlights areas of poor maintainability which require product improvement, modification or change of design.
2. It permits user to make an early assessment of whether the predicted downtime, the quality, quantity of personnel, tools and test equipment are adequate and consistent with the needs of system operational requirements.

Types of system maintenance actions:

A) corrective maintenance

- Actions taken to restore a failed system to operational status,
- Usually involves replacing or repairing the component that is responsible for the failure of the overall system,
- Corrective maintenance is performed at unpredictable intervals because a component's failure time is not known *a* ***priori*** and
- The objective of corrective maintenance is to restore the system to satisfactory operation within the shortest possible time.

Cont.

- **Diagnosis of the problem**
  – Maintenance technician takes time to locate the failed parts or otherwise satisfactorily assess the cause of the system failure
- **Repair and/or replacement of faulty component**
  – Action is taken to address the cause, usually by replacing or repairing the components that caused the system to fail
- **Verification of the repair action**
  – Once components have been repaired or replaced, the maintenance technician must verify that the system is again successfully operating

B) preventive maintenance

- **The practice of replacing components or subsystems before they fail to promote continuous system operation**
- **The preventive maintenance schedule is based on:**
  - Observation of past system behavior
  - Component wear-out mechanisms
  - Knowledge of components vital to continued system operation
- **Cost is always a factor in the scheduling of preventive maintenance**
  - Reliability may be a factor, but cost is a more general term because reliability & risk can be expressed in terms of cost
  - In many circumstances, it may be financially better to replace parts or components that have not failed at predetermined intervals rather than wait for a system failure that may result in a costly disruption in operations

C) Inspections

- Used to uncover hidden failures (also called dormant failures)
- In general, no maintenance action is performed on the component during an inspection unless the component is found failed causing a corrective maintenance action to be initiated
- Sometimes there may be a partial restoration of the inspected item performed during an inspection
  - For example, when checking the motor oil in a car between scheduled oil changes, one might occasionally add some oil in order to keep it at a constant level

Maintenance Downtime

- There is time associated with each maintenance action, *i.e.* amount of time it takes to complete the action.
- This time is referred to as ***downtime*** & defined as **the length of time an item is not operational**
- **There are a number of different factors that can affect the length of downtime**
  - Physical characteristics of the system,
  - Repair crew availability,
  - Spare part availability & other ILS factors and
  - Human factors & Environmental factors
- There are two Downtime categories for these factors: Waiting Downtime & Active Downtime.

Types of Maintenance Downtime

Waiting Downtime

- The time during which the equipment is inoperable, but not yet undergoing repair
- For example, the time it takes for replacement parts to be shipped, administrative processing time, etc.

Active Downtime

- The time during which the equipment is inoperable and actually undergoing repair
- The active downtime is the time it takes repair personnel to perform a repair or replacement
- The length of the active downtime is greatly dependent on human factors and the design of the equipment
- For example, the ease of accessibility of components in a system has a direct effect on the active downtime

Cont.

❖ Maintainability is a **function of the design of the system,** the **personnel available at the necessary skill levels,** the procedures available to perform the maintenance, the test equipment available, and the environment in which the maintenance must be performed.

❖ **Maintainability is measured by Mean-Time-To-Repair (MTTTR).**

$$MTTR = \frac{\sum_{i=1}^{n} \lambda_i Rp_i}{\sum_{i=1}^{n} \lambda_i}$$

where

n = number of subsystems

λ_i = failure rate of i^{th} system

R_{Pi} = Repair time for the i^{th} unit

Probability of Repair Within the Allowable Downtime

To calculate the probability of performing a maintenance action within an allowable time interval use:

$$M(t) = 1 - e^{-t / MTTR}$$

Where:

t = Allowable downtime

MTTR= Expected downtime (MTTR)

Mean-Time-To-Repair

The total corrective maintenance time divided by the total number of corrective maintenance actions during a given period of time.

Example: What is the probability of completing an action within 5 hours if the MTTR = 7 hours?

Solution: $M(t) = 1 - e^{-t/MTTR} = 1 - e^{5/7}$

$= 1 - .4895 = .5105$

There is approximately a 51% probability of completion.

Availability

- Availability is thus defined as the probability that an item will be available when required or as the proportion of total time that an item is available for use.

- May be defined as the probability an item is operable & can be committed at the start of a mission when the mission is called for at any unknown (random) point in time. Example: For a lamp with a 99.9% availability, there will be one time out of a thousand that someone needs to use the lamp and finds it is not operating.

Availability issues deal with at least three main factors for:-

1 - increasing time to failure

2 - Decreasing downtime due to repairs or scheduled maintenance and

3 - Accomplishing items 1 and 2 in a cost be effective manner.

As availability grows, the capacity for making money increases because the equipment is in service a larger percent of time.

Availability analysis of the system requires a knowledge:

(1) How the components are functionally connected.

(2) The failure process of the component.

(3) The method of operation and the definition of the failure.

(4) The repair or maintenance policy

The three common measures of availability are:

1. Inherent Availability (A_I)
2. Achieved Availability (A_A)
3. Operational Availability (A_o)

Inherent Availability (A_I)

This is the **ideal state for analyzing availability.** The **only considerations are the MTBF and the MTTR. This measure does not take into account the time for preventive maintenance** and assumes repair begins immediately upon failure of the system. This can also be defined as **steady – state availability.**

The measure for inherent (potential) availability (A_I) is :

$$A_I = \frac{\mu}{\lambda + \mu} = \frac{MTBF}{MTTR + MTBF}$$

Where: λ = Failure rate = 1/ MTBF

μ = Repair rate = 1/MTTR

Example: A system has an MTBF of 2080 hours and a MTTR of 10 Hours. What is the inherent availability of the system?

Solution:

$$A_I = \frac{2080}{10 + 2080} = 0.9952 \text{ or } 99.52\%$$

Achieved Availability (A_A)

Achieved availability **is somewhat more realistic in that it takes preventive maintenance into account** as well as **corrective maintenance.** The assumption here is that, as in A_I, **there is no loss of time waiting for the maintenance action to begin.**

The measure for **achieved (final) availability (A_A)** is :

$$A_A = \frac{MTBMA}{MTBMA + MMT}$$

Where :-

✓MTBMA is the mean time between maintenance actions both preventive and corrective.

✓MMT is the mean Maintenance Action Time, and MMT is further decomposed into the effects of preventive and corrective maintenance and is given as:

$$MMT = \frac{F_c \overline{M}_{ct} + F_p \overline{M}_{pt}}{F_c + F_p}$$

Where: F_c is the number of corrective maintenance actions per 1000 hours

F_p is the number of preventive maintenance actions per 1000 hours

$\overline{M}_{ct}$ is the mean active time for corrective maintenance (MTTR)

$\overline{M}_{pt}$ is the mean active time for preventive maintenance

Example : A system has a MTBMA of 110 hours, a F_c of ½, a F_p of 1, and M_{CT} of 2 hours, and M_{PT} of 1 hour. What is A_A ?

Solution :

First calculate MMT as :

$$\frac{(1/2)\,(2)\; + (1)\,(1)}{1\; +\; 1/2} = 1.33$$

Then determine A_A : A_A =

$$\frac{110}{110\; +\; 1.33} = 0.988 \;\text{ or } 98.8\%$$

Operational Availability (A_o)

This is what generally **occurs in practice.** Operational availability takes into account that the maintenance response is not instantaneous, repair parts may not be in stock as well as other logistics issues.

The measure of **operational (actual) availability A_0** is :-

$$A_o = \frac{MTBMA}{MTBMA + MDT}$$

Where MDT is mean down time.

Example:- given MTBMA = 168 Hours and MDT = 4hours

Solution : $A_o = \frac{168}{168 + 4} = 0.977$ or 97.7%

Availability for Constant Failures Rates and Mean Repair Rates

The steady – state availability was given earlier as:

$$\mathbf{A} = \frac{\mu}{\lambda + \mu} = \frac{\text{MTBF}}{\text{MTTR} + \text{MTBF}}$$

The instantaneous availability, (probability) that an item will be available at time T is:

$$A = \frac{\mu}{\lambda + \mu} + \frac{\mu}{\lambda + \mu} * \text{Exp}\ [- (\lambda + \mu) t]$$

When t is large, the expression reduces to : A $= \dfrac{\mu}{\lambda + \mu}$

Example : Given exponential failure rates and repair rates of **λ= 5, μ =3,** determine the instantaneous availability at 0.2 hours:

Solution:

$$\mathbf{A} = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} \exp[-(\lambda + \mu) t]$$

$$= \{(\frac{3}{8}) + (\frac{5}{8}) * e^{(-1.6)}\} = .501$$

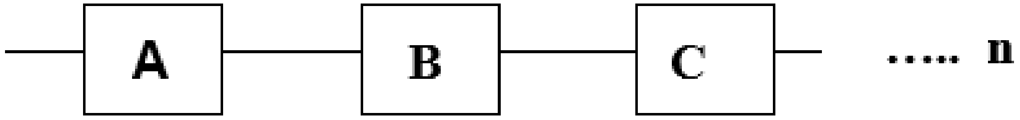
Example : The instantaneous unavailability for the previous example is:

Solution : $$A_{\mu} = 1 - \{ \frac{\mu}{\lambda + \mu} - \frac{\lambda}{\lambda + \mu} \exp[-(\lambda + \mu) t] \}$$

$$= 1 - \{(\frac{3}{8}) - (\frac{5}{8}) * e^{(-1.6)}\} = .499$$

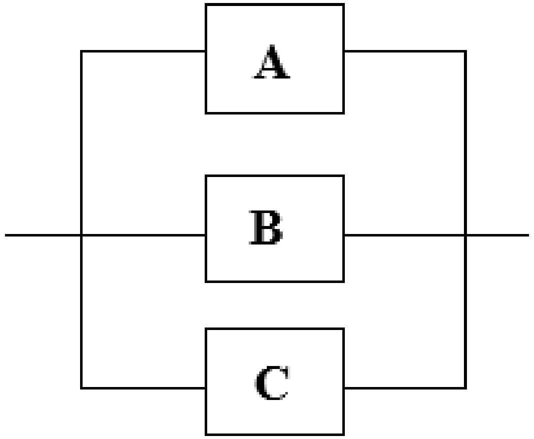
Other configurations to consider: *The steady – state [A]*

Series Configuration



$$A = \prod A_i = \prod_{I=1}^{n} \frac{\mu_i}{\lambda_i + \mu_i}$$

Parallel Configuration



$$A = 1 - \prod_{I=1}^{n} \frac{\lambda_i}{\lambda_i + \mu_i}$$

Example : Given exponential failure rates and repair times of **λ 5,μ= 3,** if two identical units are in series, determine the steady state (A):

Solution :

$$A = \prod \frac{\mu_i}{\lambda_i + \mu_i} = \left(\frac{3}{5+3}\right)\left(\frac{3}{5+3}\right) = \frac{9}{64} = 0.14063$$

Example : If the same two units in the prior example are in parallel:

Solution:

$$A = 1 - \prod_{i=1}^{n} \frac{\lambda_i}{\lambda_i + \mu_i} = 1 - \left(\frac{\lambda_1}{\lambda_1 + \mu_1}\right)\left(\frac{\lambda_2}{\lambda_2 + \mu_2}\right)$$

$$= 1 - \left(\frac{5}{8}\right)\left(\frac{5}{8}\right) = 1 - \frac{25}{64} = 0.6094$$

Capability:- deals with productive output compared to inherent productive output which is a measure of how well the production activity is performed compared to datum. This index measure the systems capability to perform the intended function on a system basis.

In other word Productivity which is the **product of efficiency multiplied by utilization.** Efficiency measures the productive work output versus the work input. **Utilization is the ratio of time spent on productive efforts to the total time consumed.**

For example, suppose **efficiency is 80% because of wasted labor/scrap generated**, and **utilization is 82.19% because the operation is operated 300dys per year out of 365 days.** **The capability is 0.8*0.8219 = 65.75%.** These numbers are frequently generated by accounting departments for production departments as a key index of how they are doing.

chapter 9,10&12(Merged)
Maintenance Planning, organizing and network analysis for planning and controlling maintenance work

Maintenance Planning is the advance preparation of selected jobs so that they can be executed in an efficient and effective manner when the job is performed at some future date.

Maintenance Planning is a process of detailed analysis to first determine and then to describe the work to be performed, by task sequence and methodology.

Maintenance Planning provides for the identification of all required resources, including skills, crew size, labor-hours, spare parts and materials, special tools and equipment.

Maintenance Planning includes developing an estimate of total cost and encompasses essential preparatory, post maintenance and restart efforts of both operations and maintenance.

Why is Maintenance Planning Needed?

- If the maintenance planning is professionally handled, the effective utilization of maintenance personnel can be increased by as much as 65% and job execution time can be reduced by as much as 40 to 50%.

The principal objectives of maintenance planning and scheduling include:-

- Minimizing the idle time of maintenance forces;
- Maximizing the efficient use of work time, material, and equipment; and
- Maintaining the operating equipment at a level that is responsive to the need of production in terms of delivery schedule and quality.

PRINCIPLES OF PLANNING

- ✓ Understand the department's mission in relation to the objectives of the company;
- ✓ Always be aware of the magnitude and trend of backlog;
- ✓ Quantify the magnitude of the resources effectively available to apply toward relief of the backlog;
- ✓ Establish a plan for the allocation of available resources to a balanced workweek, considering both long-range importance and short-range necessity;
- ✓ Categorize work consistent with planned resource allocation categories;

Cont.

- ✓Assign a planning priority (within job priority and category) to each job;
- ✓Break each job into logically sequenced tasks/activities;
- ✓Prepare a "Planning Week" schedule by phases of work planning and by task to determine progress toward completion of each week's work planning;
- ✓Work to meet this schedule. Protect it.
- ✓Measure progress and contribution.

Sequence of Planning

Scheduling (when to do the job): Scheduling is the process by which required resources are allocated to specific jobs at a time the internal customer can make the associated equipment or job site accessible.

It is the process by which jobs are matched with resources (crafts) and sequenced to be executed at certain points in time.

The maintenance schedule can be prepared in three levels depending on the horizon of the schedule.

The levels are:

(1) medium range or master schedule to cover a period of 3 months to 1 year;

(2) weekly schedule, it is the maintenance work that covers a week; and

(3) the daily schedule covering the work to be completed each day.

Maintenance Job Priority System

- The maintenance job priority system has a tremendous impact on maintenance scheduling.

- Priorities are established to ensure that the most critical and needed work is scheduled first.

- Priority systems typically include three to ten levels of priority.
- Most organizations adopt four or three level priorities.
- Table below provides classification of the priority level and candidate jobs to be in each class as identified by Duffuaa

Table :- Priorities of maintenance work

Code	Name	Time frame work should start	Type of work
1	Emergency	Work should start immediately	Work that has an immediate effect on safety, environment, quality, or will shut down the operation
2	Urgent	Work should start within 24 h	Work that is likely to have an impact on safety, environment, quality, or shut down the operation
3	Normal	Work should start within 48 h	Work that is likely to impact the production within a week.
4	Scheduled	As scheduled	Preventive maintenance and routine. All programmed work
5	Postponable	Work should start when resources are available or at shutdown period	Work that does not have an immediate impact on safety, health, environment, or the production operations

Scheduling Techniques

- Techniques are developed to develop optimum or near optimal schedules with respect to different possible performance measures.

- **These are:**

1. Gantt Charts and Scheduling Theory
2. Project Scheduling
3. Critical Path Method
4. Program Evaluation Review Techniques (PERT)

1. Gantt Charts and Scheduling Theory

- developed by Henry L. Gantt during World War II.
- The Gantt chart is a bar chart that specifies the start and finish time for each activity on a horizontal time scale.
- It is very useful for showing planned work activities vs accomplishments on the same time scale.
- It can also be used to show the interdependencies among jobs, and the critical jobs that need special attention and effective monitoring.

- The following Figure shows the simplest form of the Gantt chart in which activities are scheduled at specified dates within the month.

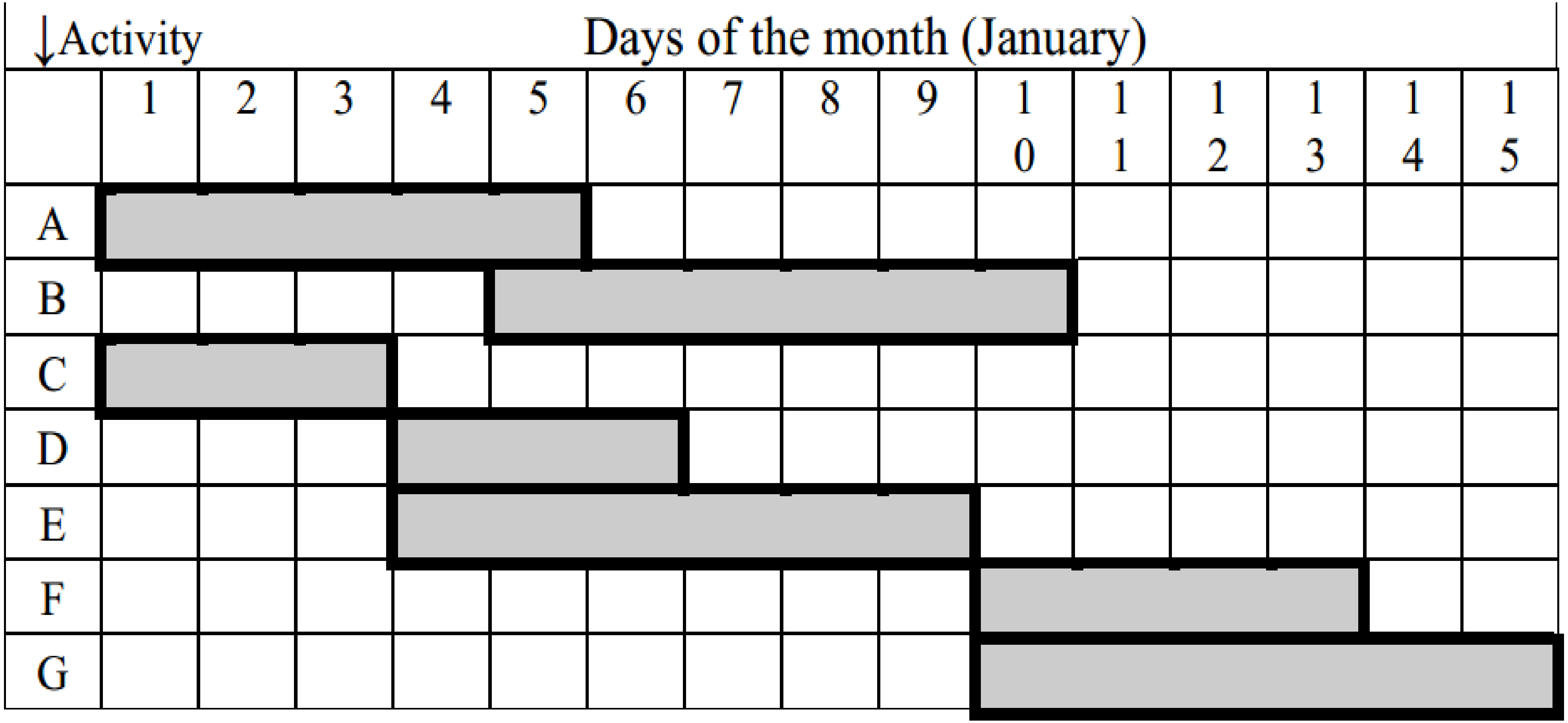


Figure. A Gantt chart representing a schedule of seven activities

Cont.

- Gantt charts can also be used to show the schedule for **multiple teams** or **equipment** simultaneously. A case in which three heavy pieces of equipment are scheduled for different jobs throughout the day as shown below.
- The chart indicates that jobs 25A and 15D are completed on schedule,
- job 25C is behind schedule by about a full day while job 25B is ahead of schedule by about a day, and
- job 41E is in progress exactly on schedule.
- Jobs 33C and 44E scheduled but have not started yet.

Cont.

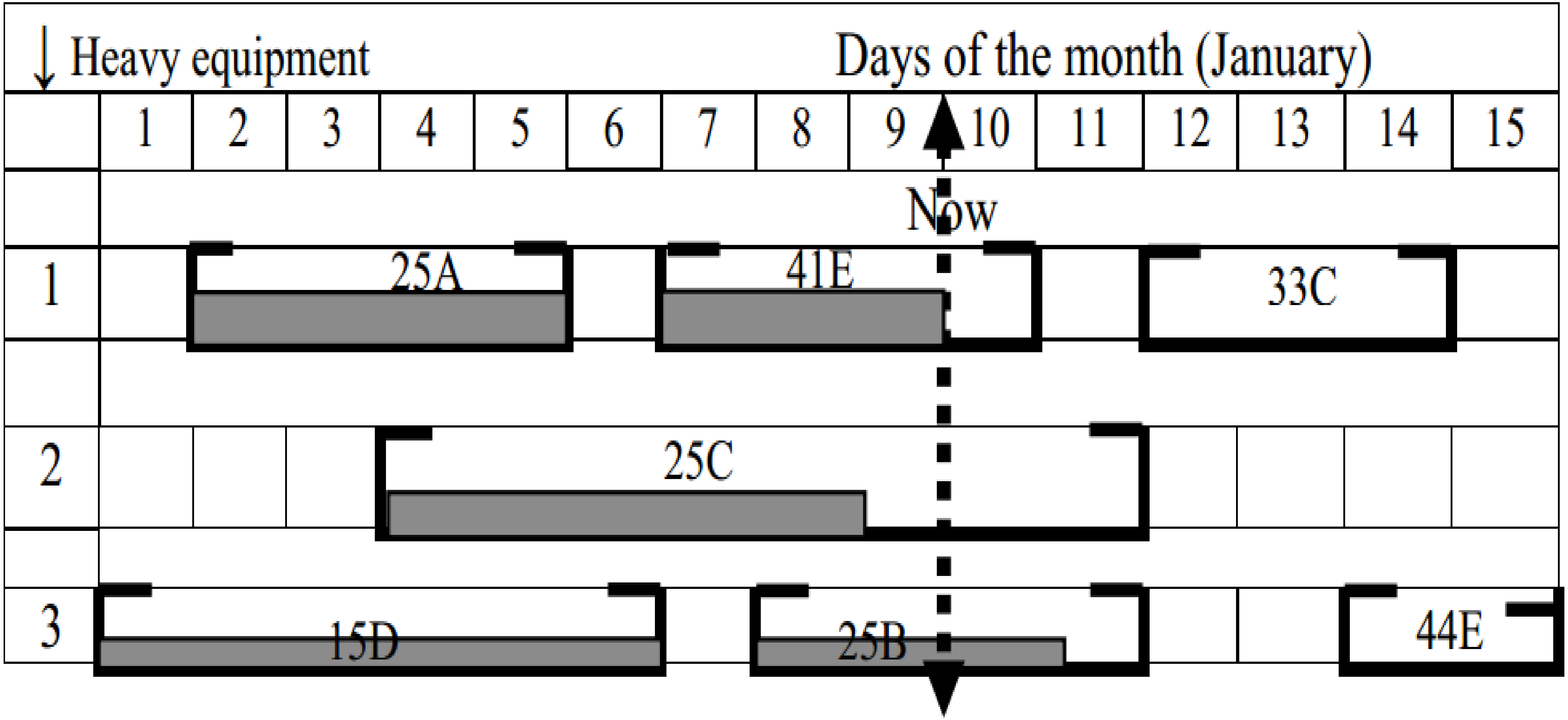


Figure. Gantt chart with progression

2 - Project Scheduling

Network Analysis for Planning and Control of Maintenance Work:-

Network analysis entails a group of techniques for presenting information relating to time and resources so as to assist in the planning, scheduling, and controlling of projects.

The information represented by network, includes the sequences, interdependencies, interrelationships, and critical activities of the project.

This is very useful for projects which are complex in nature or where activities are subject to considerable degree of uncertainty in performance time.

Applications of network techniques are very wide, but are very common in some of the following fields:

(i) Construction of buildings, bridges, highways, railways, stadiums, irrigation projects, factories, power projects etc.

(ii) Assembly line scheduling,

(iii) Development and launching of new products,

(iv) Strategic and tactical military planning,

(v) Research and development,

(vi) Market penetration programmed,

(vii) Planning of political campaigns,

(viii) Maintenance and overhauling of complicated or large machineries,

(ix) organizing big conferences etc.

Advantages of Network Technique:

1. Detailed planning provides better analysis and logical thinking.
2. Identifies the critical activities and focus them to provide greater managerial attention.
3. Network technique enables to forecast project duration more accurately.
4. It is a powerful tool for optimization of resources.
5. It provides a scientific basis for monitoring, review and control, to evaluate effect of slippages.
6. It helps in taking decision;
7. It helps in getting better co-ordination amongst related fields.
8. It is an effective management tool through a common and simple language, providing common understand.

Limitations of Network Techniques:

Network techniques have following limitations:-

i. Network technique is simply a tool to help the management; hence its effectiveness depends on how well it is used by the management.

ii. Its accuracy depends on the estimation of the data used in the network.

iii. It is useful only if it is updated regularly and decisions for corrective actions are taken timely.

Cont.

- The **two primary network programming techniques** used in project scheduling are the **critical path method (CPM)** and **program evaluation and review technique (PERT)**
- The main difference between the two is that **CPM uses a single estimate of activity time duration** while **PERT uses three estimates of time for each activity.**
- Hence, CPM is considered to be a **deterministic network method** while **PERT is a probabilistic method.**

Cont.

- Both networks consist of nodes representing activities and arrows indicating precedence between the activities.
- The objective in both CPM and PERT is to **schedule the sequence of work activities in the project** and **determine the total time needed to complete the project.**
- **The total time duration is the longest sequence of activities in the network** (the longest path through the network diagram) and is called the **critical path.**
- Before we proceed by explaining the two methods it is worth noting that **PERT and CPM are not well suited for day-to-day** independent **small jobs scheduling in a maintenance department.**

Cont.

- However, they are very useful in planning and scheduling large jobs (20 man hours or more) that consist of many activities such as machine overhauls, plant shut downs maintenance activities.
- Furthermore, a prerequisite for the application of both methods is the representation of the project as a network diagram, which shows the interdependencies and precedence relationships among the activities of the project.
- Formulating the maintenance project as a network diagram helps in viewing the whole project as an integrated system.
- Interaction and precedence relationships can be seen easily and be evaluated in terms of their impact on other jobs.

Cont.

- The project network representation will be demonstrated by an example from maintenance.
- **Next Table** shows the data for overhauling a bearing in a train cargo carriage. The data shows the normal, crash duration, their corresponding costs, and precedence relationships for each activity.
- The term crash time refers to the minimum time the job can be accomplished in (by committing more resources), beyond which no further reduction in the job duration can be achieved.
- At this duration any increase in the resources for this job will increase the cost without reducing the duration.

Activity	Description	Time (Min.)		Costs($)		Immediate precedence relationship
		Normal	Crash	Normal	Crash	
A	Dismantling	50	30	100	150	0
B	Repair of bolster pockets	67	50	120	150	A
C	Repair side frame rotation stop legs	90	60	150	200	A
D	Check friction blocks and all springs	35	25	50	75	A
E	Repair bolster rotation stop gibs.	35	25	140	170	B
F	Repair side frame column wear plates	55	40	100	130	C
G	Repair bolster pivot	210	150	250	300	E
H	Assemble	65	45	120	150	D, F and G
I	Painting	40	30	80	100	H

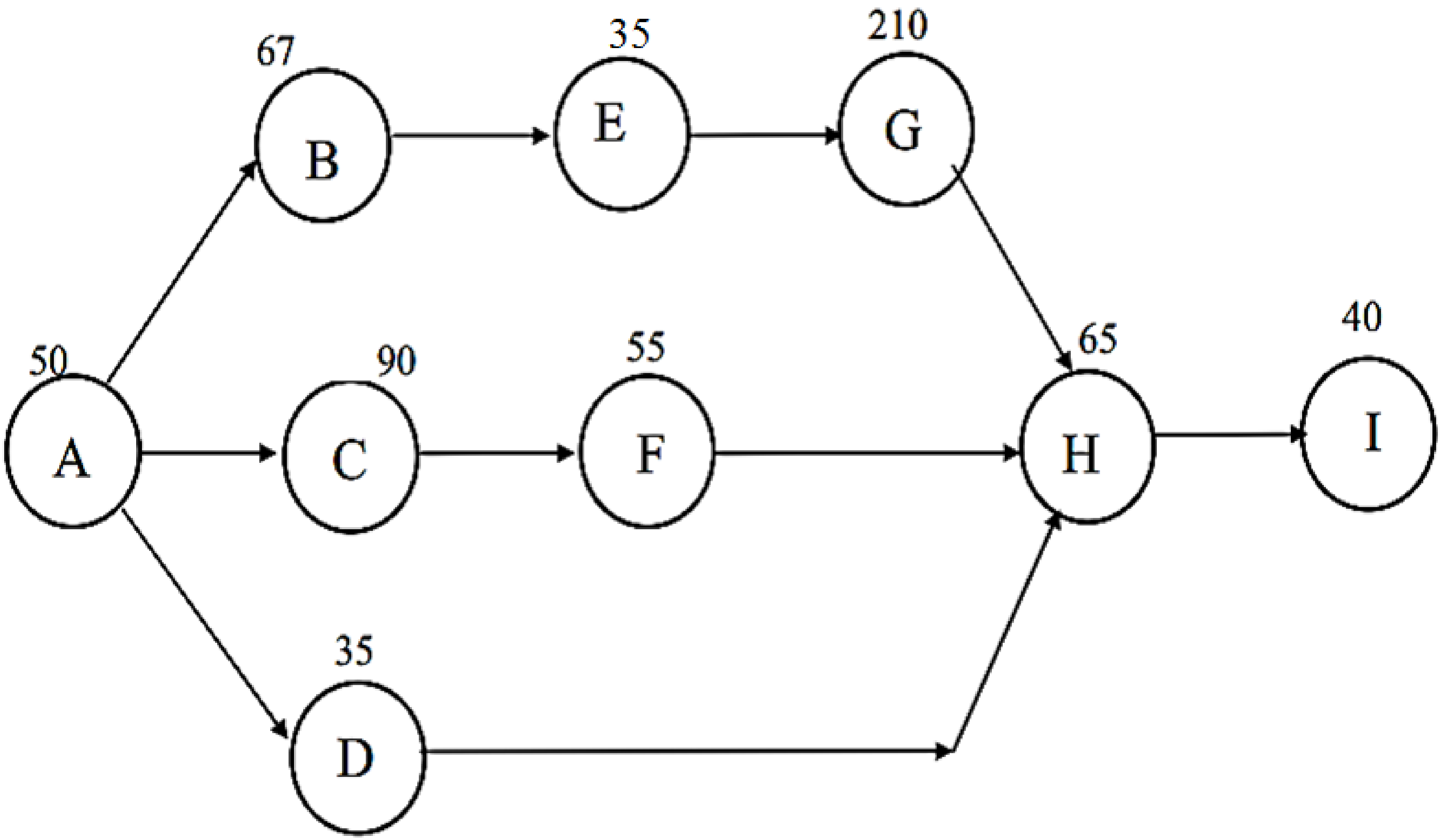
Cont.

Next Figure shows the network corresponding to the data in the table.

It starts with node A with no predecessor activity and it is represented by a circle nearby a number indicating the time.

A itself is a predecessor for three activities B, C, and D drawn as three circles connected to A by arrows to indicate the precedence relation with A. Other activities (nodes) are traced back similarly. The resulting network is terminated by node I that has no successor.

Cont.



Cont.

- There are many paths through the network in Figure starting from the first node to the last node. The longest one is called the **critical path** and the summation of the activity times along that path is the **total project duration.**
- Jobs in the critical path are called **critical** in the sense that any delay in these jobs would cause a **delay in the whole project.**
- All other paths include slack times (sometimes called floats), i.e. The amount of extra time that activities in the path can be delayed without delaying the completion time of the whole project.
- Activities that are not in the critical path may have some slack times, i.e., delaying this activity for one reason or another will not delay the whole project. In this example there are three possible paths shown in the next Table.
- Critical activities must be monitored carefully and adhere to their specified schedules; however, non-critical activities can be used for leveling the resources due to the available slacks.

Path	Path activities	Project duration	Sum
1	A-B-E-G-H-I	50+67+35+210+65+40	467
2	A-C-F-H-I	50+90+55+65+40	300
3	A-D-H-I	50+35+65+40	190

Clearly the **project duration is 467 min** and the **critical path is the first path (A-B-E-G-H-I).** Paths 2 and 3 have slacks of 167 and 277 min respectively. In this example, it was easy to go through all possible paths to find the one with the longest time; however, it would be extremely difficult to do the same for larger projects having a large number of activities and more complicated relationships between them.

A systematic approach for identifying the critical path is known as the critical path method (CPM).

3) Critical Path Method

To identify the critical path using the CP method we need to follow the following steps:

1. Develop the project network diagram as shown in the previous section;
2. Perform the CPM calculation to identify the critical jobs (there are jobs on the critical paths and non-critical jobs (which are jobs with float);
3. Perform project crashing to (determine minimum times for each job) reduce project duration and investigate the cost tradeoffs; and
4. Level the resources in order to have uniform manpower requirements to minimize hiring, firing, or over time requirements.

Cont.

The critical path calculation includes two phases. The first phase is the **forward pass** (starting with the first node and proceeding to the last node). In this phase, the **earliest start time, ES,** and **earliest finish time, EF**, are determined for each activity. The earliest start time Esi for a given activity, i, is the earliest possible time in the schedule that activity i can be started.

Its value is determined by summing up the activity times of the activities lying on the longest path leading to it.

The earliest finish time Efi for a given activity i, is its **earliest start time plus its activity time Tai.**

The calculations for the bearing overhaul example are shown in next Table.

Activity i	Longest forward path	earliest start time (ES_i)	activity time (T_{ai})	earliest finish time (EF_i)
A	-	0	50	50
B	A	50	67	117
C	A	50	90	140
D	A	50	35	85
E	A – B	117	35	152
F	A – C	140	55	195
G	A – B – E	152	210	362
H	A – B – E – G	362	65	427
I	A – B – E – G – H	427	40	467

Cont.

The second phase is the backward pass (starting with the last node and proceeding back to the first node).

We start this phase by assuming that the **total project time Tcp,** is **the earliest finish time**, EF, of the last activity found in the forward pass.

In this phase, the **latest finish time, LF,** and **latest start time, LS**, are **determined for each activity.**

The **latest finish time Lfi** for a given **activity, i**, is the latest possible time that activity i must be completed in order to finish the whole project on schedule. Its value is determined by - **subtracting from Tcp the activity time along the longest path leading backward from the last node.**

For the last activity of the schedule, LF is set to be the **total time duration of the project, Tcp.** The latest finish time, **LFi,** for a given activity, i, is **its <u>latest finish time minus its activity time Tai.</u>**

The calculations for the bearing overhaul example are shown in Table.

Activity i	**longest forward** path	**Length of longest path**	LF_i T_{CP} =467	T_{ai}	LS_i
I	-	0	467	40	427
H	I	40	427	65	362
G	I – H	105	362	210	152
F	I – H	105	362	55	307
E	I – H – G	315	152	35	117
D	I – H	105	362	35	327
C	I – H – F	160	362	90	372
B	I – H – G – E	350	117	67	50
A	I – H – G – E – B	417	50	50	0

The last step in the analysis of the network is to determine the **slack time for each activity Si**

It can be determined by the **difference** between **the latest and the earliest start time of the activity.** The calculations are shown in Table below.

Activity i	LS_i	ES_i	LF_i	EF_i	S_i
A	0	0	50	50	0
B	50	50	117	117	0
C	372	50	362	140	322
D	327	50	362	85	277
E	117	117	152	152	0
F	307	140	362	195	167
G	152	152	362	262	0
H	362	362	427	427	0
I	427	427	467	467	0

Cont.

Note that the activities along the **critical path (A-B-E-G-H-I) have zero slack times.**

Activities **not lying on the critical path have positive slacks,** meaning that **they could be delayed by an amount of time equal to their slack without delaying the project completion time**.

The construction of the time chart should be made taking into consideration the available resources, and must take full advantage of the CPM calculation. In some circumstances it might not be possible to schedule many activities simultaneously because of personnel and equipment limitations. **The total float for non-critical activities can be used to level the resources and minimize the maximum resource requirement.**

4) Program Evaluation Review Techniques (PERT)

- CPM uses a single estimate of the time duration based on the judgment of a person.
- PERT, on the other hand, incorporates the uncertainty by three time estimates of the same activity to form a probabilistic description of their time requirement.
- Even though the three time estimates are judgmental they provide more information about the activity that can be used for probabilistic modeling.

The three values are represented as follows:

Oi = optimistic time, the time required if execution goes extremely well;

Pi = pessimistic time, which is the time required under the worst conditions &

mi = most likely time, which is the time required under normal condition.

The activity duration is modeled using a beta distribution with **mean (μ)** and **variance (σ^2)** for each activity **i** estimated from the three points as follows:

$$\mu_i = \frac{o_i + p_i + 4m_i}{6}$$

$$\sigma_i^2 = \left[\frac{p_i - o_i}{6}\right]^2$$

Estimated means are then **used to find the critical path** in the same way of the CPM method. In PERT, the total time of the critical path is a random variable with a value that is unknown in advance. However, additional probabilistic analysis can be conducted regarding possible project durations based on the assumption that the **total time of the project** may be approximated by a **normal probability distribution with mean μ and variance σ^2 estimated as:-**

$$\mu = \sum \mu_i$$

$$\sigma^2 = \sum \sigma i^2$$

Where i is an activity in the critical path

Using the above approximation we can calculate the probability with which a project can be completed in any time duration, T, using the normal distribution as follows:

$$pr(T_{cp} \leq T) = \Pr\left(Z \leq \frac{T-\mu}{\sqrt{\sigma^2}}\right) = \Phi(z)$$

Where Φ is the **distribution function of the standard normal distribution.**

- Tables exist for evaluating any probability under the standard normal distribution.

To illustrate the PERT analysis, consider the previous example with additional time estimates shown in Table below.

Activity	Description	Time (min)			Estimates	
		O	m	P	Mean	Variance
A	Dismantling	40	50	60	50	11.09
B	Repair of bolster pockets	60	67	74	67	5.43
C	Repair side frame rotation stop legs	85	90	95	90	2.79
D	Check friction blocks and all springs	32	35	38	35	4.00
E	Repair bolster rotation stop gibs	30	35	40	35	2.79
F	Repair side frame column wear plates	50	55	60	55	2.79
G	Repair bolster pivot	170	210	250	210	177.69
H	Assemble	59	65	71	65	4.00
I	Painting	35	40	45	40	2.79
Total					467	213.37

CONT

The critical path calculations lead to the same critical path obtained in the previous CPM calculations. The total project time is expected to be 467 min.

The estimated variance is 213.37 min. The probability that the project will complete in 467 min can be calculated from the standard normal distribution to be 0.5, or the project has a 50% chance of completing in 467 min. The probability that the project may finish in 500 min can be calculated as:

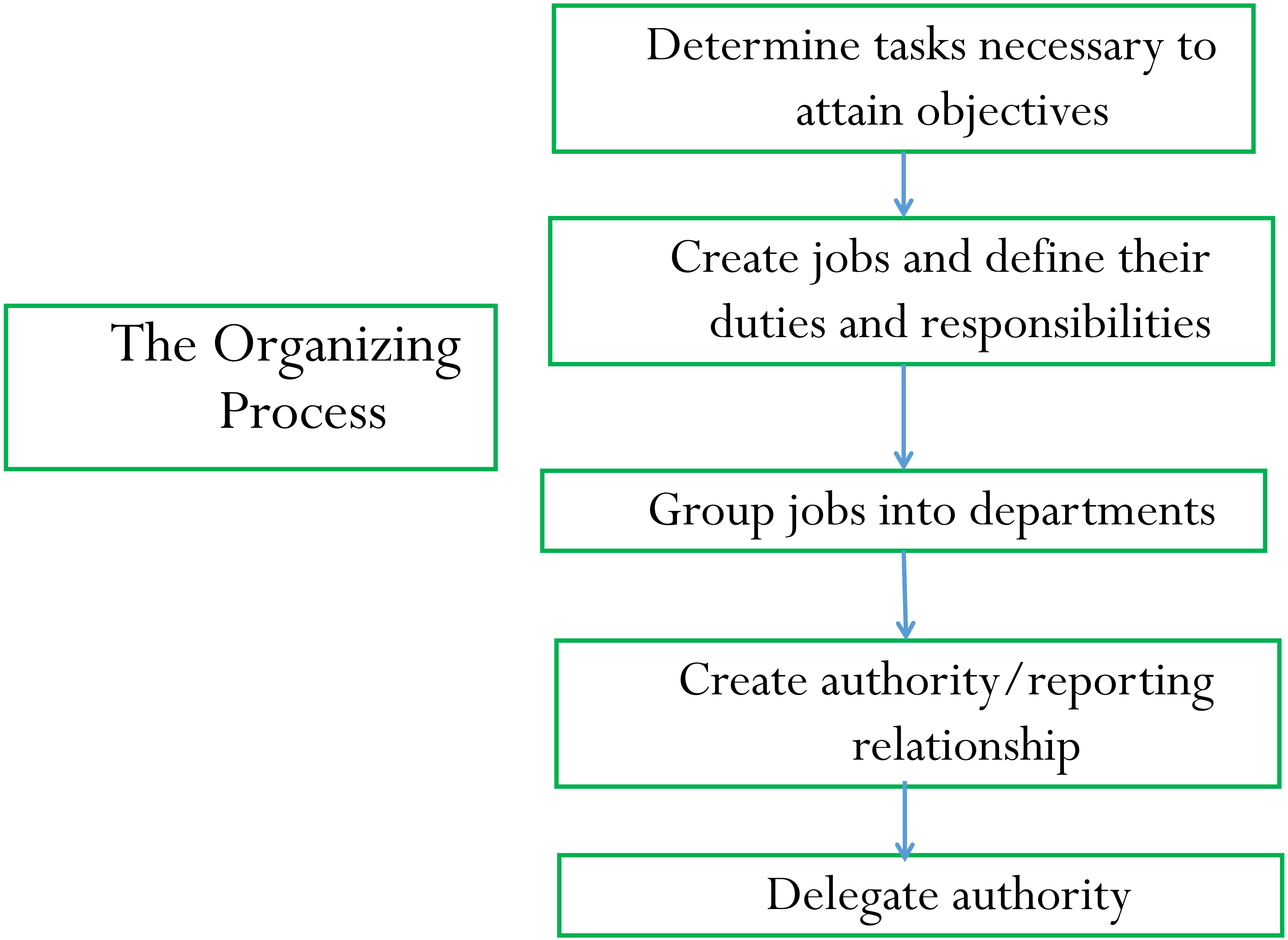
$$\Phi\left(\frac{500-467}{\sqrt{213.37}}\right)=\Phi(2.26)=0.9881$$

meaning that, the chance of completing the project in 500 min is almost 99%.

Maintenance Organization

Organizing is the process of arranging people and physical resources to carry out plans and accomplish organizational objectives.

Organization is the process of identifying, classifying, grouping and assigning various activities/responsibilities/ and delegating authority and establishing relationships for the purpose of enabling to work most effectively together in the accomplishments of objectives:



The Organizing Process
Determine tasks necessary to attain objectives
Create jobs and define their duties and responsibilities
Group jobs into departments
Create authority/reporting relationship
Delegate authority

Basic Management Organization Concepts

1. Establish reasonably clear division of authority with minimal overlap.

Authority can be divided functionally, geographically, or on the basis of expediency; or it can rest on some combination of all three

2. Keep vertical lines of authority and responsibility as short as possible.

Stacking layers of intermediate supervision, or the over application of specialized functional staff aides, must be minimized.

3. Maintain an optimum number of people reporting to one individual.

Good organizations limit the number of people reporting to a single supervisor to between three and six.

4. Fit the organization to the personalities involved.

Factors Affecting Maintenance Organization

1. Type of operation.

- ✓ Maintenance may be predominant in a single area—buildings, machine tools, process equipment, piping, or electrical elements and this will affect the character of the organization and the supervision required.

2. Continuity of operations.

- ✓ Whether an operation is a 5-day, single-shift or, say, a 7-day, three shifts makes a considerable difference in how the maintenance engineering department is to be structured and in the number of personnel to be included.

3. Geographical situation.

- ✓ The maintenance that works in a compact plant will vary from that the one that is dispersed through several buildings and over a large area.

4. Size of plant.

- ✓ As with the geographical considerations above, the actual plant size will dictate the number of maintenance employees needed and the amount of supervision for this number.

5. Scope of the plant maintenance department.

- ✓ Inclusion of responsibility for a **number of secondary functions** means **additional manpower and supervision.**

6. Work-force level of training and reliability.

- ✓ This highly variable characteristic has a strong impact on maintenance organization because it dictates how much work can be done and how well it can be performed.

Lines of Reporting for Maintenance

- ✓ Many feel that a maintenance department functions best when it reports directly to top management.

- ✓ If maintenance supervision considers itself part of production and its performance is evaluated in this light, it should report to the authority responsible for plant operations.

- ✓ Maintenance engineering should report to a level that is responsible for the plant groups which it serves—plant manager, production superintendent, or manager of manufacturing — depending on the organization

Specialized Personnel in Maintenance Organization

Technically Trained Engineers

Combining engineering and supervisory skills assures:

- Rapid maturity of newly graduated personnel
- Increasingly expeditious work performance through shorter lines of communication.
- An early introduction into the art of handling personnel, making them more adaptable to all levels of plant supervision.
- Less resistance to new ideas.

Staff Specialists

The use and number of staff specialists—electrical engineers, industrial engineers, metallurgists — depends on availability, required need for specialization, and the economics of a consulting service's cost compared to that of employing staff experts.

Clerical Personnel

Paperwork should be minimized consistent with good operations and adequate control; the clerical staff should be designed to relieve supervision of routine paperwork that it can handle. The number of clerks used varies from 1 per 100 employees to 1 per 20 to 25 employees.

Manpower Requirements

- ✓ The number of employees— labor and supervision — to assure adequate plant maintenance coverage depends upon many factors.

- ✓ Each plant must be treated as a separate problem with a consideration of all its unique aspects.

Hourly Personnel:

- Ratio of Maintenance Manpower to Total Operation Personnel
- Crafts That Should Be Included.

Selection and Training

a. Selection – Craft Personnel

Bases for selection could be:

- education,
- general intelligence,
- mechanical aptitude, and
- past experience

b. Training—Craft Personnel

- Formal Instruction
- Informal Instruction
- On-the-Job Training

c. Selection—Supervisory Personnel

Although there are advantages in selecting people entirely from among maintenance employees, others who display leadership potential should be considered.

d. Training—Supervisory Personnel

This training consists of initial orientation; a formalized, sustained program of leadership training; and on-the-job coaching and consultation.

- ✓ **Orientation** gives the candidate basic data about the management team she/he is joining and about company and department policy.

- ✓ Included also are facts about the scope of her/his personal responsibilities and the limits of the authority delegated to her/him.

- ✓ ***Training*** ensuring continued effectiveness and improved performance should include such subjects as human relations, conducting of interviews, teaching methods, safety, and many more.

- ✓ Goals of this part of the program should head toward increasing the candidate's effectiveness as supervisor, instilling a feeling of unity with fellow managers, and enhancing personal development.

CONT

On-the-job coaching is especially important for the embryo supervisor.

There is no substitute for frequent, informal, personal contact with a superior concerning current technical, personnel, or personal problems.

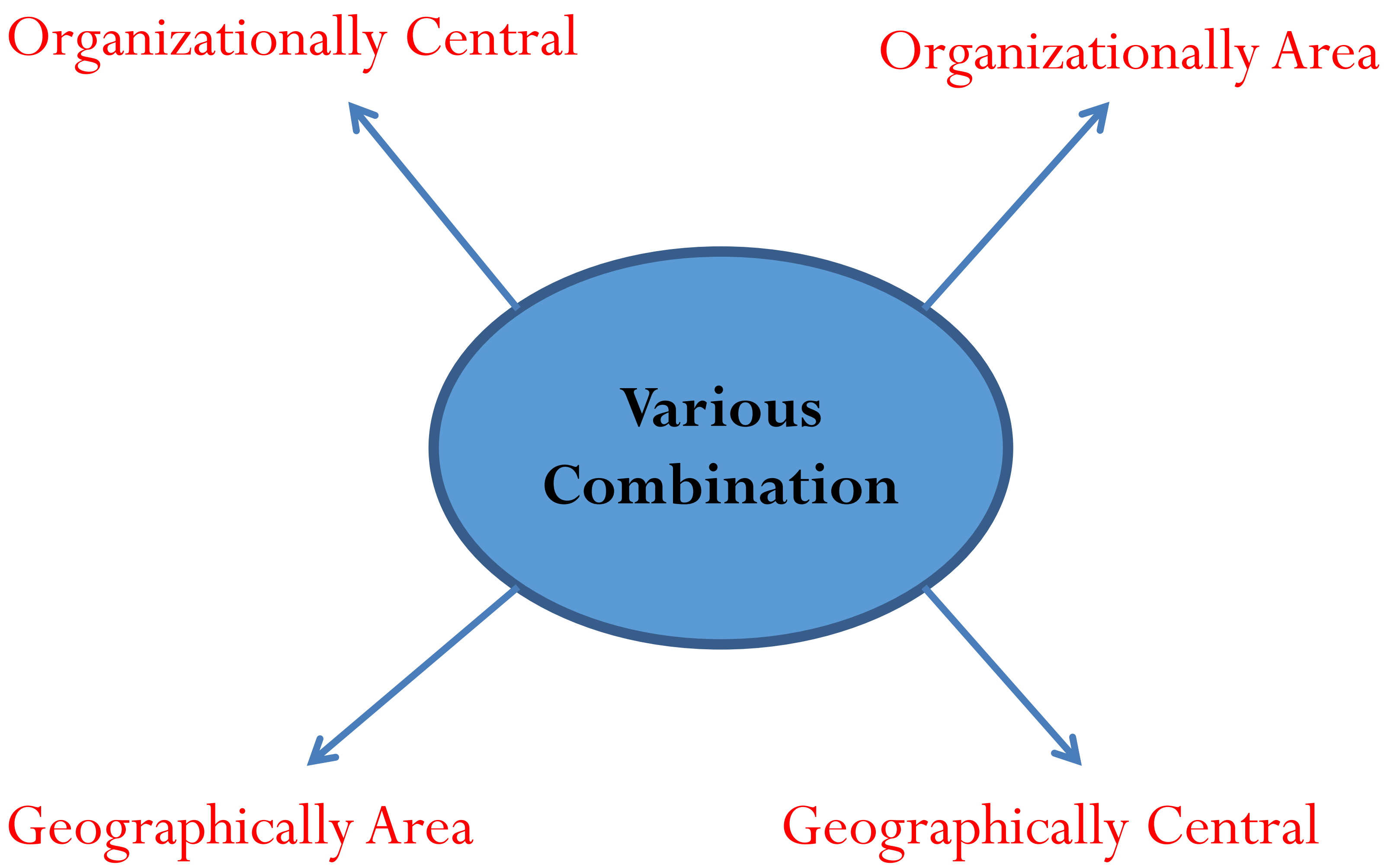
This type of development is a force for high morale and job satisfaction.

It should include both praise and criticism, the former sincere, the latter constructive.

Area and Centralized Maintenance Control

- ✓ **Geography:** The distribution of men, tools, material, etc., to positions within the plant site, geographically central meaning all men, tools, and material located at one point.

- ✓ **Organization:** The direct organization control of craftsmen, including their supervision, scheduling, and guidance, organizationally central meaning the control of all maintenance in the facility by one person below the level of site manager.


Organizationally Central
Organizationally Area
Various Combination
Geographically Area
Geographically Central

CHAPTER 11&13(Merged)
Spares provisioning and reconditioning process

11. SPARES PROVISIONING

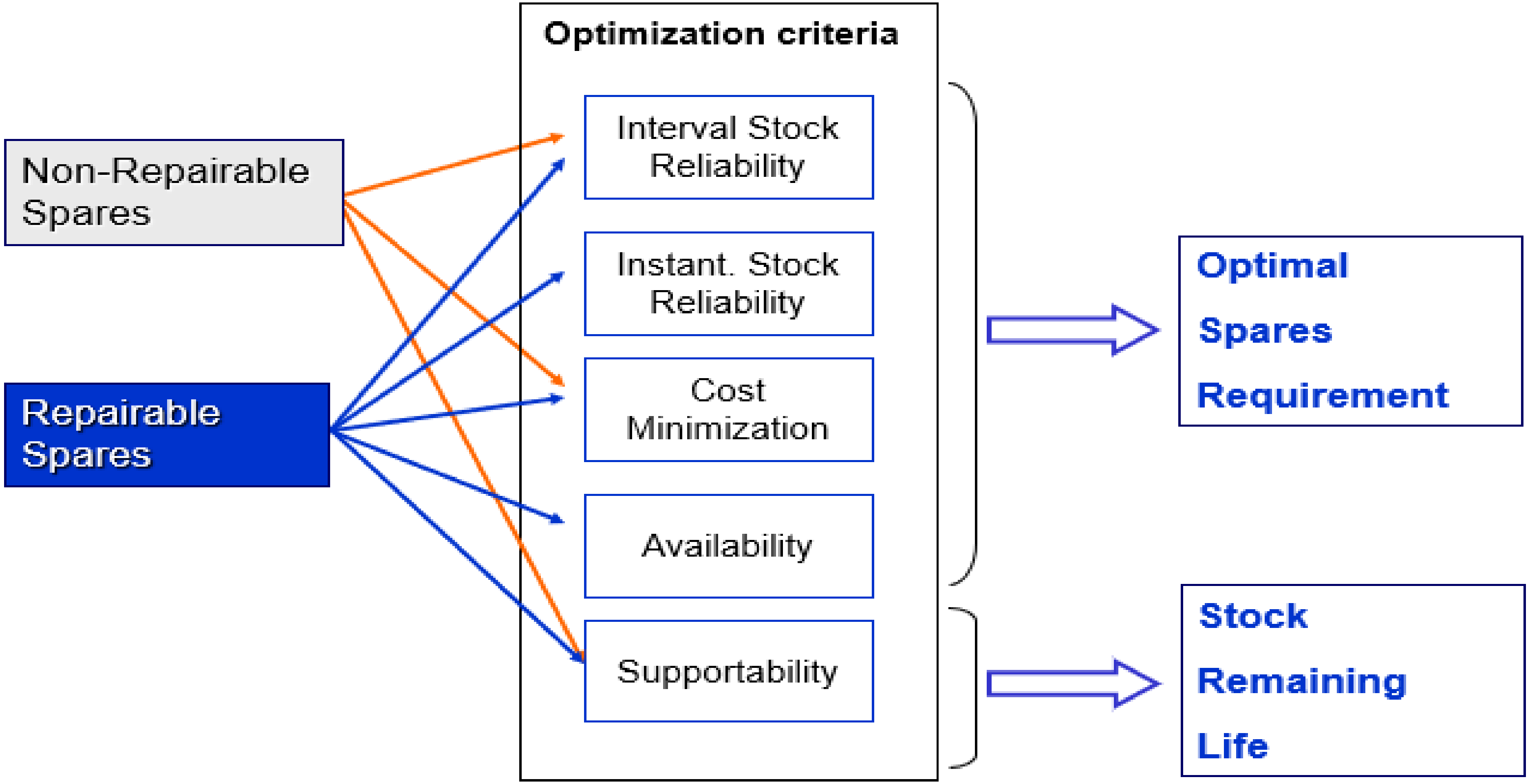
Industry with a high level of investment, such as the oil and gas industry, needs a high level of availability.

Product support and its related issues such as ***spare parts*** play an important role in ***maintaining a system at a desired level of availability.***

Reliability performance is a critical factor for ***product support and spare parts planning*** which can be influenced by operational environment. Therefore, ***all influence factors (covariates) on reliability performances must be considered in order to predicate the required number of spare parts.***

In general, ***provisioning means "providing" or making something available.*** The term is used in a variety of contexts.

11.1 Spares management



Criteria for Decision Making

1. Instant reliability
2. Interval reliability
3. Cost minimization
4. (Process) Availability

Cont'd

Due to the ***technology*** and ***economic*** issues, it is not possible to design a system without failure. Therefore, it is necessary to adopt appropriate and well-scheduled activities regarding support and spare parts to assure the desired level of availability throughout the system's life.

However, spare parts provisioning is a ***complex problem and requires an accurate analysis of all factors*** that may affect the ***required number of spare parts.***

Different reliability based statistical approaches have been developed for spare parts provision. The methods can be categorized in two main groups;

i) ***Analytical methods, and***

ii) ***Simulation methods.***

The analytical methods are based on ***Renewal theory for non-repairable items. Birth and Death process have been frequently used for repairable items*** in the ***analytical methods.***

The Monte Carlo method is one of the main simulation methods

In the reliability-based spare parts provision,

✓First step is to identify the reliability performance and failure rate of the item.

✓Second the number of the required spare parts and the probability of spare part availability can be estimated, However, to have an effective prediction, any factors which have an influence on the reliability performance of the item must be considered.

The reliability performance of an item can be influenced by different factors such as:

- ***The operational environment,***
- ***Geographical location,***
- ***Design material, maintenance history,***
- ***Operator and***
- ***Maintenance crew skill, etc.***

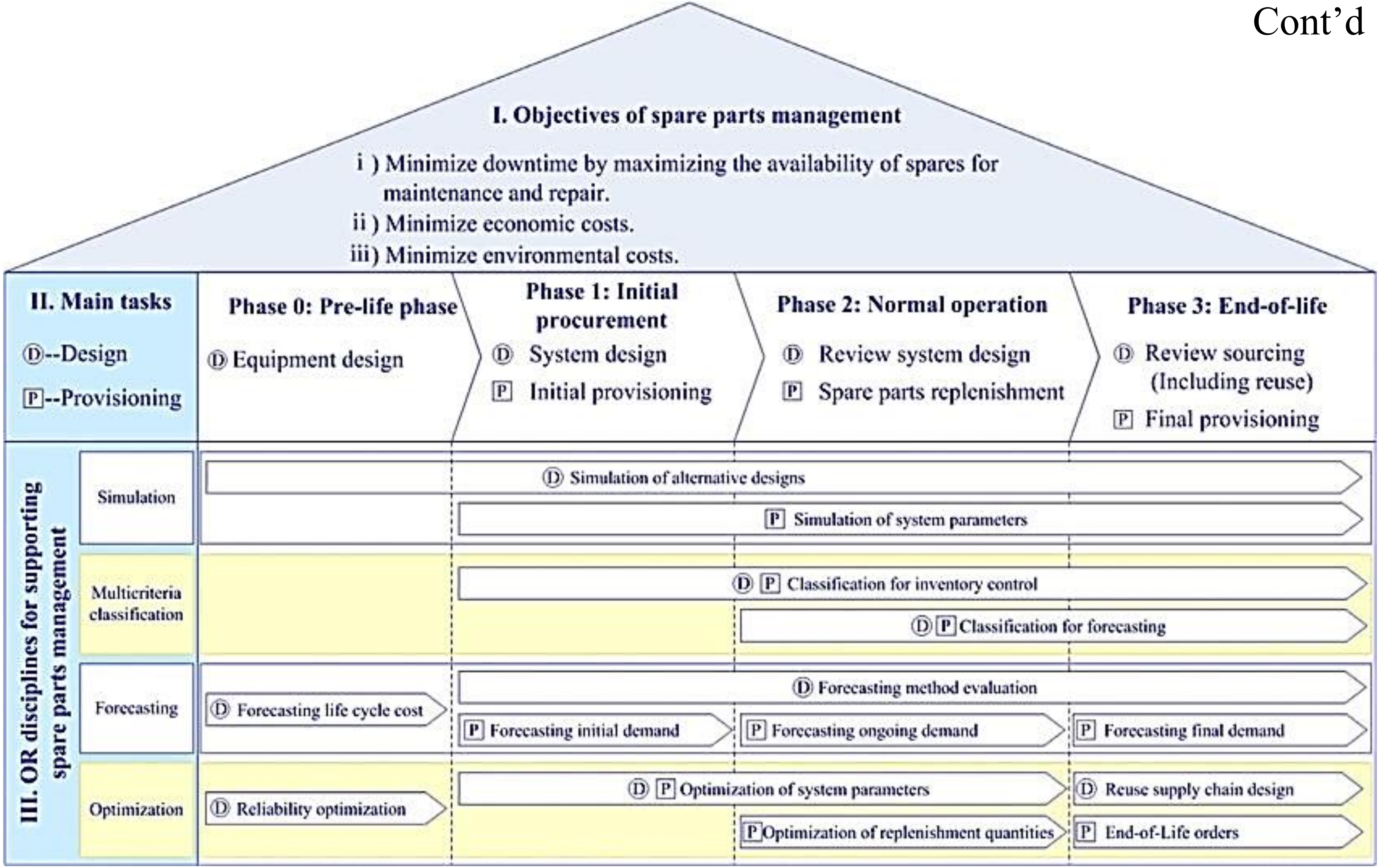
The factors that may have an influence on the reliability performance of an item are referred to as ***covariates.*** ***Ignoring such covariates may lead to wrong result in reliability performance analysis and consequently on spare parts provisioning.***

Cont’d

Spare parts *are held to reduce the consequences of equipment downtime, playing an important role in achieving the desired equipment availability at a minimum economic cost.*

The gap between theory and practice of spare parts management is ***investigated from the perspective of software integration, maintenance management information systems.***

Cont’d


I. Objectives of spare parts management
i) Minimize downtime by maximizing the availability of spares for maintenance and repair.
ii) Minimize economic costs.
iii) Minimize environmental costs.
II. Main tasks
D--Design
P--Provisioning
Phase 0: Pre-life phase
D Equipment design
Phase 1: Initial procurement
D System design
P Initial provisioning
Phase 2: Normal operation
D Review system design
P Spare parts replenishment
Phase 3: End-of-life
D Review sourcing (Including reuse)
P Final provisioning
III. OR disciplines for supporting spare parts management
Simulation
D Simulation of alternative designs
P Simulation of system parameters
Multicriteria classification
D P Classification for inventory control
D P Classification for forecasting
Forecasting
D Forecasting life cycle cost
D Forecasting method evaluation
P Forecasting initial demand
P Forecasting ongoing demand
P Forecasting final demand
Optimization
D Reliability optimization
D P Optimization of system parameters
P Optimization of replenishment quantities
D Reuse supply chain design
P End-of-Life orders

Objectives of spare parts management

The key questions in spare parts management are to decide ***which items are to be stocked as spare parts,*** ***when to (re)order them*** and ***how many items to (re)order.*** In this decision-making process, we should be clear about the objectives.

1. ***Maximizing spares' availability,***
2. ***Minimizing the economic costs.*** Is the sum of the inventory holding costs, stock-out penalty costs and ordering costs, and
3. ***Minimize enviromental costs***

Main tasks of spare parts management through equipment lifecycle process

Equipment life cycle cost is closely connected to investment and management of spare parts inventories. In general, the equipment lifecycle process can be divided into three main phases, namely

1. ***Initial procurement phase,***
2. ***Normal operation phase, and***
3. ***End-of-life phase.***

The main tasks of spare parts management for each phase of the product lifecycle process are summarized below.

Initial procurement phase :

- When a complicated piece of equipment is bought, spare parts are often bought simultaneously to satisfy the needs of equipment maintenance.
- Then a decision must be made on the spare parts initial provisioning, and an inventory and forecasting system must be designed in advance.

Cont’d

Normal operation phase :

- ❖When equipment is used by the user, preventive maintenance may be carried out to prevent failure, while corrective maintenance is carried out as failures occur
- ❖In order to satisfy the needs of maintenance, a certain number and kinds of spare parts are supplied.
- ❖Successful equipment management depends on the proper execution of spare parts control is needed.
- ❖Therefore, the inventory system and forecasting parameters should be optimized (or at least improved) to provide sustainable supply support according to the operational requirements of the equipment.

Cont’d

End-of-life phase :

- In Phase 3, a ***fundamental issue of supply chain design*** is whether products, or their components, should be reused, leading to refurbishment or remanufacturing, If not, then it may sometimes be necessary to set a final order on spare parts according to the demand patterns at the end of the product life cycle (known as an ‘all-time buy’ or ‘last-time buy’).
- This prompts a number of design issues to be resolved, including the methodologies for classifying and forecasting the demand, taking into account that no more orders may be made and simulating the consequences of alternative strategies for these parts in the end-of-life phase.

Forecasting

Forecasting spare parts demand is a basic requirement of spare parts management.

Because of the demand characteristics of spare parts, it is very difficult to accurately forecast demand in this area.

the critical challenges of inventory management in service parts are ***inaccuracy of service parts forecasts ranks number two in the top ten challenges.***

So it has been a hot topic in the industrial field as well as in academic research.

There are many forecasting techniques and this section restricts attention to those forecasting methods which have been suggested for spare parts.

From a product lifecycle perspective, there are ***three kinds of forecasting tasks*** namely ***forecasting initial demand, ongoing demand and demand over the final phase.***

Forecasting approaches categorized in to three groups these are:

a. Time-series based forecasting

- A time series is defined as a time-ordered sequence of observations taken at regular intervals (e.g., hourly, daily, weekly, monthly, quarterly, annually).
- Time-series forecasting is based on the assumption that future values of the series can be estimated from past values.
- If there is sample historical data, time-series based forecasting is commonly used to forecast spare parts demand in practice.

b. Reliability based forecasting

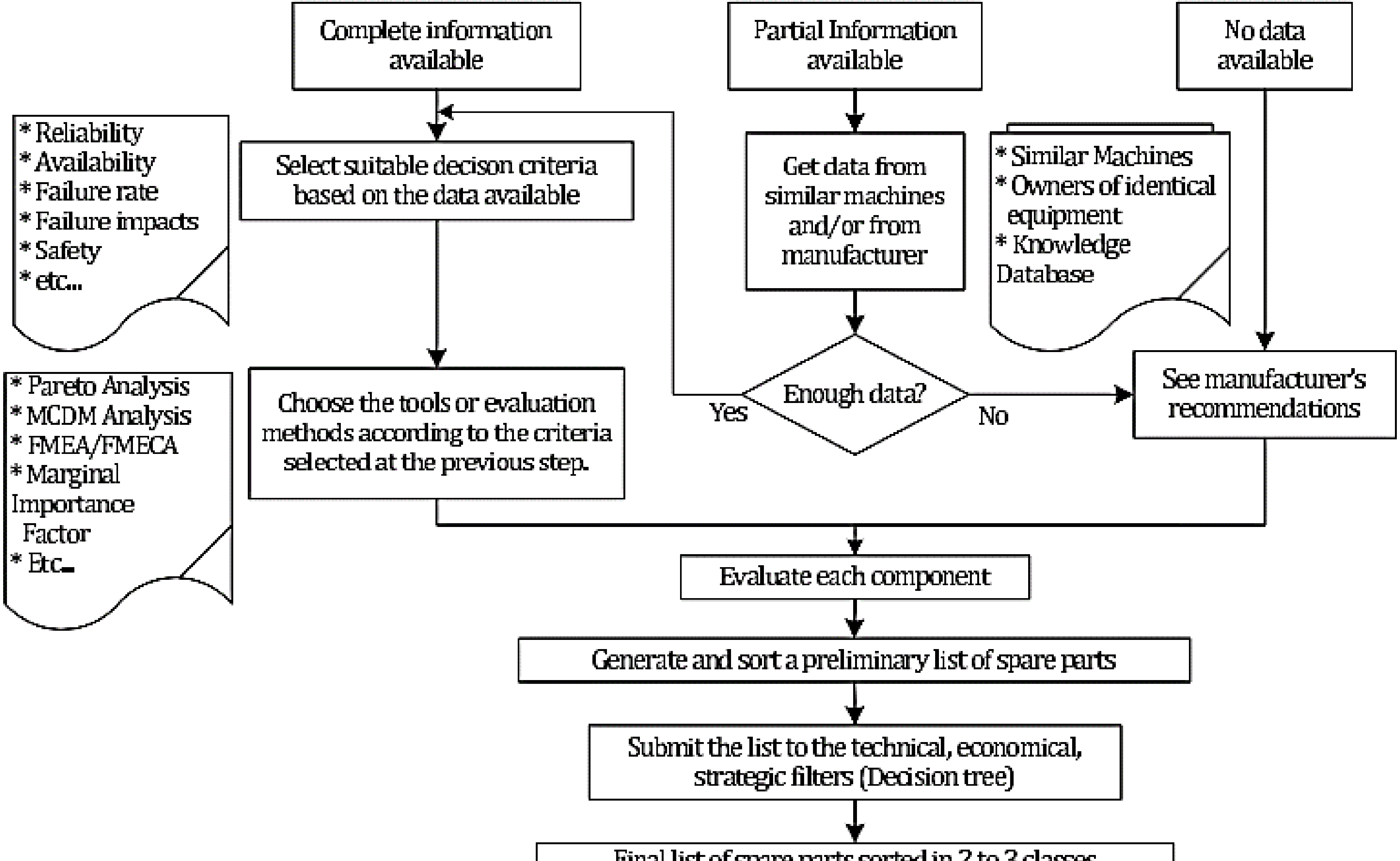
- The most appropriate time-series based forecasting approach depends on the availability of historical data.
- In some cases, there is little time series data available to forecast the future demand. In such cases, practitioners can use reliability and maintenance variables to forecast spare parts demand, as long as these variables are known or may be estimated.
- These models may also prove beneficial when more extensive historical demand data are available, depending on their predictive strength.

c. Judgmentally based forecasting

- There is some element of judgment in almost all forecasting processes.
- In some cases, a forecast may be purely judgmental. For example, for new products, it may not be possible to generate a statistical forecast because of the lack of historical data on sales.
- In other cases, a statistical forecast may be produced, but is then amended by a demand planner in the light of the planner's judgment about changes in the internal or external environments.

11.2 Spare Parts Identification process

To stay in business, equipment manufacturers are expected not only to meet the needs identified by the client, but also to anticipate these needs and to demonstrate that the products and services offered are equivalent, if not superior to what is available on the market.


Complete information available
Partial Information available
No data available
* Reliability
* Availability
* Failure rate
* Failure impacts
* Safety
* etc...
Select suitable decison criteria based on the data available
Get data from similar machines and/or from manufacturer
* Similar Machines
* Owners of identical equipment
* Knowledge Database
* Pareto Analysis
* MCDM Analysis
* FMEA/FMECA
* Marginal Importance Factor
* Etc...
Choose the tools or evaluation methods according to the criteria selected at the previous step.
Yes
Enough data?
No
See manufacturer's recommendations
Evaluate each component
Generate and sort a preliminary list of spare parts
Submit the list to the technical, economical, strategic filters (Decision tree)

Decision tree with filters

- ✍Decisions are based on the manufacturers’ recommendations or on information from owners of similar equipment.
- ✍When complete information is available, then the decision-maker chooses the criteria according to which the components will be evaluated to determine if they should be on the list of spare parts.
- ✍A list of potential criteria is given in previous figure.
- ✍According to the criteria retained, evaluation and final decision-making methods are to be selected next.
- ✍Each component of the equipment is then evaluated according to the criteria and a total score is obtained.
- ✍A list of potential methods is also provided in previous figure.
- ✍A ranking of the components based on the final scores gives an ordered list of potential spare parts.

Desion tree

A ranking of the components based on the final scores gives an ordered list of potential spare parts. Once the preliminary list of spare parts is established, it is subjected to filters to select the parts to hold in stock and those to be supplied as needed.

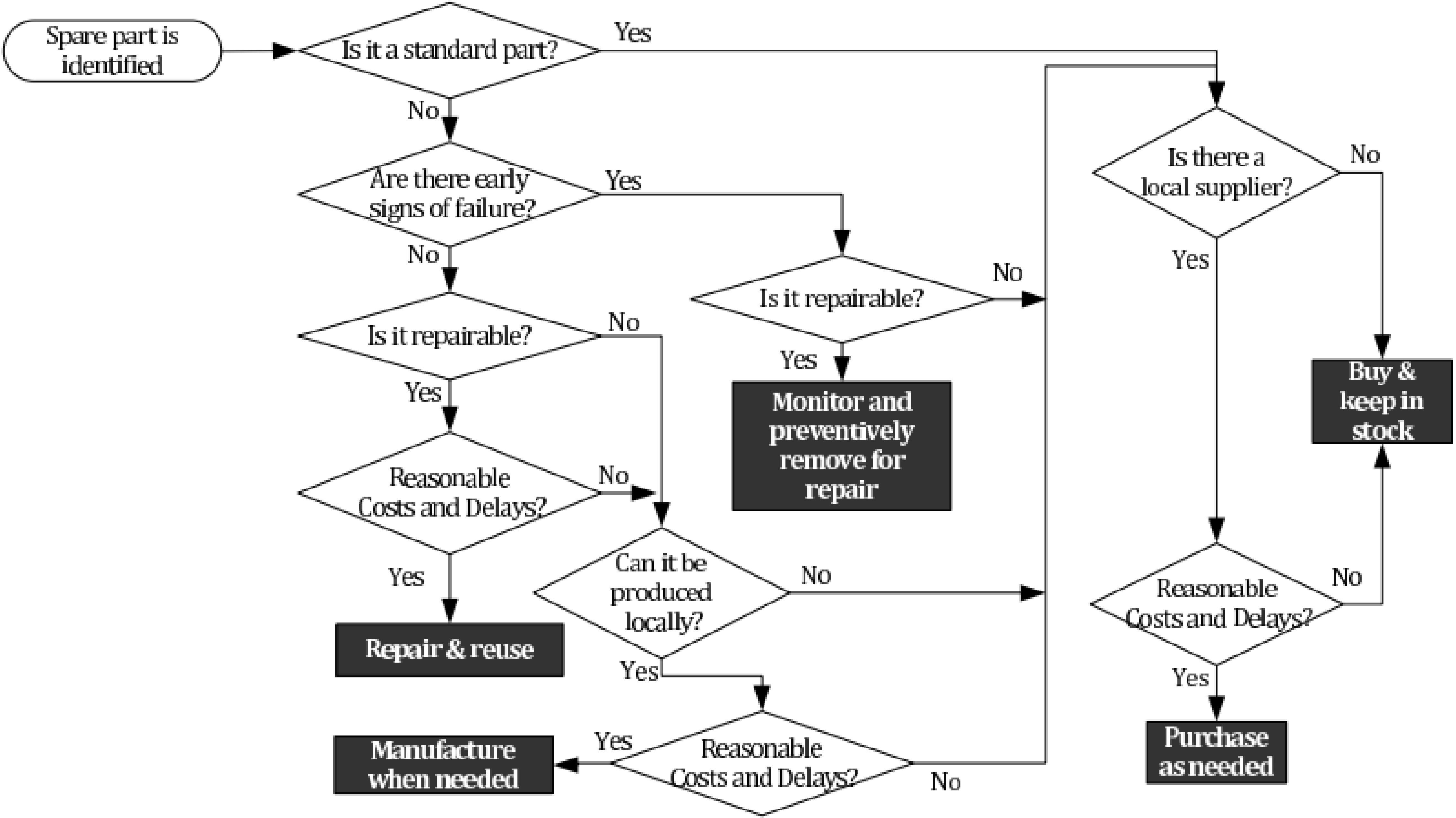
This tree takes into account the cost of acquisition or production, repair costs, delays, whether there are early signs of failure or not, and if the component is a standard part or not. A standard part is a generic mass-produced part readily available at reasonable to low cost (e.g., seals, nuts and bolts, high replacement rate parts).

Selected components are then ranked in order of importance. This classification allows to pay more attention to the components considered as being more important, especially if the list of spare parts includes a large number of components and the resources available are limited or scarce.

Decision criteria most often used to justify that a spare part must be kept in stock to serve as a replacement are: criticality, reliability, availability, impacts of failure, failure rate and maintenance costs incurred in case of failure.

Any component i with RGi ratio greater than 1, is then kept in store as a spare.

$$RG_i = \frac{\text{Indirect Costs}}{\text{Direct Costs}}$$

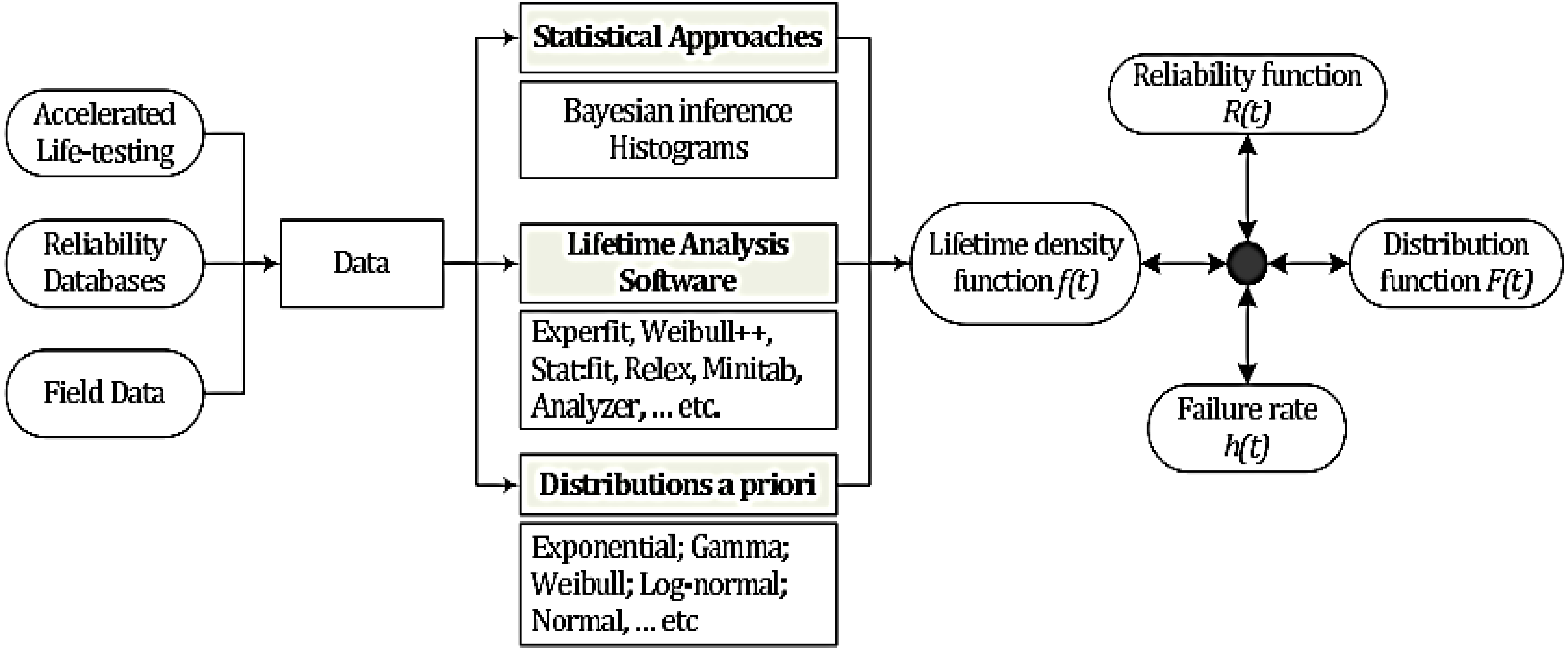


Spare part is identified
Is it a standard part?
Yes
No
Are there early signs of failure?
Yes
No
Is it repairable?
No
Yes
Monitor and preventively remove for repair
Is it repairable?
No
Yes
Reasonable Costs and Delays?
No
Yes
Repair & reuse
Can it be produced locally?
No
Yes
Reasonable Costs and Delays?
Yes
No
Manufacture when needed
Is there a local supplier?
No
Yes
Buy & keep in stock
Reasonable Costs and Delays?
No
Yes
Purchase as needed

Determination of the required quantity of non repairable spares

For each component requiring spare parts, it is important to estimate the required amount of spares needed throughout the economic life cycle of the equipment.

To achieve this, one must estimate the average number of replacements at failure and, where applicable, the average number of preventive replacements.



Determination of the required quantity of repairable spares

A failed component, according to its degradation state, is repaired and put back in a “as new condition” or put in a state where it can resume operation.

The acquisition cost of these repairable components is generally high. If the repair is found to be not feasible for technical, economical or other reasons, the failed component is sent to a recycling or disposal facility.

13. Reconditioning processes

To recondition a machine or piece of equipment means to repair or replace all the parts that are damaged or broken by repairing it, cleaning it, or replacing parts

Synonyms: restore, repair, renew, overhaul

Main elements which wants recondition before putting the vehicle on the lot

The reconditioning process ensures each vehicle is in good working order. Here are a few of the parts may need repair or replace before putting the vehicle on the lot:-

- A/C and heater
- Lights and radio
- Warning lights
- Engine and airbag warning lights
- Brakes
- Exhaust system
- Ignition system

Used Car Inspection Checklist

Car Model: ....

Car Mileage: ....

Car Year: ....

Car Vehicle Identification Number (VIN) : ....

Brakes	Yes	No
Do the brakes make grinding noises?		
Does the car pull to one side when applying the brakes?		
Does the parking brake work properly?		

Engine	Yes	No
Do the battery terminals have signs of corrosion?		
Do the exhaust pipes emit blue or black smoke?		
Does the engine emit an odor?		
Does the engine leak oil or fluids when it is on or off?		
Does the engine make any strange noises, such as knocks, ticks or hisses?		

Cont'd

Exterior	Yes	No
Are there any cracks in the windshield?		
Are there any dents or scratches on the body?		
Do all doors, trunk and hood open and close properly?		
Do the headlights, brights, directional lights and tail lights work?		
Is there any rust in the door edges, hinges or trunk?		

Interior	Yes	No
Are there any dashboard warning lights illuminated?		
Can you adjust the seats?		
Do all the gauges work?		
Do all the power windows work?		
Do the hazard lights work?		
Do the locks all work from the inside and outside?		
Do the windshield wipers, blades and fluid work?		
Does the air conditioner work?		
Does the heater work?		
Does the stereo work?		

Notes: ....

....

....

Cont'd

Miscellaneous	Yes	No
Does the car alarm work?		
Does the owner have a title?		
Does the sunroof work?		
Manual: does each gear shift smoothly?		
Manual: does the car make noises when in reverse?		

Steering	Yes	No
Does the car or steering wheel shake or vibrate at any speed?		
Does the steering wheel align with the wheels?		
Is there any resistance from the steering wheel when turning?		

Tires	Yes	No
Do the tires have any cuts or cracks?		
Is the spare tire inflated?		
Is the tread unevenly worn?		
Is there a functional spare tire and jack?		

Example: Battery Reconditioning

- The process of ***reconditioning a car battery*** is an operation that attempts to restore ***the ability of a dead battery*** to ***receive and store charge.***
- This process is a simple and straightforward operation that can be done in ***two ways.*** Almost the ***same method that uses different mediums.***
- The first option is restoring a dead car battery with the use of ***Battery Chem*** while the other method is carrying out the same process with the use of the ***Epsom Salt battery recipe solution.***

During the process, ***both of the agents*** ***break down the sulfate buildups within the battery and its lead plates.*** This ***allows them to regain their ability to take in electricity and store it then convert it to power.*** Both of these processes are suitable for dead automotive batteries.