CERTIFICATE

This is to certify that the dissertation entitled “Reliability Centered Maintenance, a case study of NC Frit Glass Coating Machine”, being submitted by **Mr. Ashok Kumar** in partial fulfilment for the award of the degree of Master of Engineering in Production and Industrial Engineering, is a bonafide work carried out by him under my guidance and supervision.

The results embodied in this Thesis have not been submitted to any other University or Institute for the award of any degree.

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RELIABILITY CENTERED MAINTENANCE
A CASE STUDY OF NC FRIT GLASS COATING MACHINE

BY

ASHOK KUMAR

A Major Project Report Submitted in Partial Fulfilment of

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EXECUTIVE SUMMARY

Recently, there has been tremendous pressure on manufacturing and service organisation to be competitive and provide timely delivery of quality products. Maintenance, as a system plays a key role in achieving organisational goals and objectives. It contributes to reducing cost, minimizing equipment downtime, and consequences of failure, increasing productivity and providing reliable equipment that are safe and well configured to achieve timely delivery of orders to customers

The purpose of this thesis is to present maintenance as an integrated system that needs to be planned, engineered and controlled using different techniques.

Chapter 1 presents the brief description of Reliability centered maintenance (RCM) methodology and of objective of the case study.

Chapter 2 presents maintenance as a system. Brief description of process of equipment maintenance, types of maintenance, implementation of autonomous maintenance, application of computers in maintenance, need of training to maintenance workers and maintenance training activities are presented.

Chapter 3 presents the Reliability Centered Maintenance (RCM) methodology, misconception about RCM, benefits and pitfalls in implementing RCM,

Chapter 4 presents the analysis of breakdowns by applying the different techniques described in RCM methodology. The techniques covered in this chapter include, cause and effect diagram, failure mode and effect analysis, logic tree analysis over all equipment effectiveness.

Chapter 5 presents the analysis of overall equipment effectiveness and scope for future work.

CONTENTS

CHAPTER 1 : INTRODUCTION

1.1 INTRODUCTION

Increased competition and customer demand for the timely delivery of high quality products have forced manufacturers to meet customer requirements through process, rather than inventory in any supply chain. One of the prerequisite for this is reliable equipment, process and system. Further with the adoption of automation, which requires very high investments in equipment to achieve the targeted rates of return on investment, the equipment has to be reliable and capable of being kept reliable without costly work stoppages, repairs and maintenance. The strategies for maintenance of equipment have undergone a tremendous changes over the last five decades of industrialization. Complexities of equipment, increasing costs of maintenance and high cost associated with down time have all contributed to devise more meaningful and result oriented maintenance practices. Controlling maintenance costs, together with improving plant reliability and capacity has become an area of escalating attention in the ever increasing need to increase manufacturing competitiveness. A number of new maintenance philosophies have evolved and proven themselves in assisting maintenance managers in providing better plant utilization at lower costs. Amongst these are preventive maintenance, predictive and proactive maintenance, condition based maintenance and more recently Reliability Centered Maintenance (RCM). RCM strategy employs preventive, predictive and proactive maintenance technologies in an integrated manner to increase confidence that a machine will operate dependably over an extended life. RCM is an upcoming maintenance philosophy in the field of maintenance management to improve the reliability of manufacturing systems. RCM provides a structured and logical approach to determine the maintenance requirements of any physical asset in its operating context. This methodology helps in identifying what causes the functional failure of an equipment and what are the consequences of any failure. The focus shifts on the elimination of machine failure, rather than the prediction of failures. Along with the preventive, predicted and proactive approaches, the RCM philosophy include knowledge-based diagnostics of samples to incorporate a learning component within the program. The element of knowledge is permanently embedded within the working practices so that the organization does not repeat bad practices and make continuous error. RCM focuses on 'system function' approach. Complex redundant systems have reliability directly engineered into their design. The flow chart of RCM methodology is presented in the Fig. 1.1

System Selection and Information Collection

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System Boundary Definition

↓

System Description and Functional Block Diagram

↓

System Functions and Functional Failures

↓

Failure Mode and Effect Analysis

↓

Logic Tree Analysis

↓

Tasks Selection

Fig: 1.1 Flow Diagram of RCM Methodology

1.2 OBJECTIVE OF THE CASE STUDY

In this study, RCM is considered as a methodology to improve the reliability and performance of the equipment. A case of NC Firt Glass Coating Machine has been taken for the application of RCM . The objectives of the study are:

- To understand and present the different aspects of maintenance management (Chapter 2).
- To study and present the concept and the methodology of RCM (Chapter 3).
- To undertake a case study from the manufacturing environment for the study and implementation of RCM.

The following subsystems of NC Frit Glass Coating Machine are studied as follows:

* Funnel Carry and Lifting System

* Funnel Stopper System

* Funnel Gauging System

* Axes Drive System

* Frit Glass Tank Unit

Methodology: For improving the reliability of the equipment, RCM is used. The various tools and techniques applied in the case study are as follows:

- Data Collection (three years)
- Functional Failure Analysis
- Failure Mode and Effect Analysis
- Logic Tree Analysis
- Overall Equipment Effectiveness (OEE) Analysis

  The above methodology is applied to real life case study in an electronics company for NC Frit Glass Coating Machine.

CHAPTER 2 : MAINTENANCE MANAGEMENT

2.1 INTRODUCTION

Maintenance is war. The enemies are breakdown, deterioration and the consequences of all the types of unplanned events. The soldiers are the maintenance department. The civilians, we protect are production office workers, drivers and all the other users of our organization's assets. Maintenance is defined as the combination of activities by which equipment or a system is kept in, or restored to, a state in which it can perform its designated functions. It is an important factor in product quality and can be used as a strategy for successful competition. To produce a high level of quality, production equipment must operate within, specifications that are attainable by timely maintenance actions. The new paradigm of business is to focus on streamlining, reducing the inputs and making the process more responsive and efficient. As a result, the mission of maintenance must conform with the continuous improvement of all process in the organization. The new mission includes the idea that maintenance should work endlessly to reduce, and where possible, eliminate the need for maintenance. The purpose of equipment maintenance is to sustain adequate equipment condition at all times in order to have uninterrupted production. The basics of preventive maintenance form the foundation of a maintenance management system. Once the preventive maintenance foundation is in place, inventory, work orders, computerized maintenance management systems, and training of maintenance manpower form the next level. Involving the operator for routine maintenance, along with the predictive and RCM techniques, build on this foundation. With the availability of sufficient plant data, the organization can focus on its asset management strategy by Total Productive Maintenance (TPM) and maximize its life cycle profits. Once this level is achieved, the organization should strive for continuous improvement & bench marking. A typical maintenance system is shown in figure. 2.1

As a matter of convenience, equipment maintenance is divided into two types. Operator maintenance and specialized maintenance. This separates the tasks of equipment maintenance according to who will carry out the work, the production department or the maintenance department. Who should take the initiative in implementing equipment maintenance?. It is the task of the maintenance department. It is useful for maintenance manager and maintenance personnel to go back to the basics and to deepen their understanding of equipment maintenance in order to deploy successful maintenance activity company wide.

2.2 THE PROCESS OF EQUIPMENT MAINTENANCE

Equipment maintenance involves decisions about "what part or section of what equipment requires what maintenance method." Then it is necessary to draft a standard maintenance procedure, a maintenance calendar, and based on this, carry out systematic maintenance, which will result in the prevention of breakdown.The process of equipment maintenance is given in Fig. 2.2.

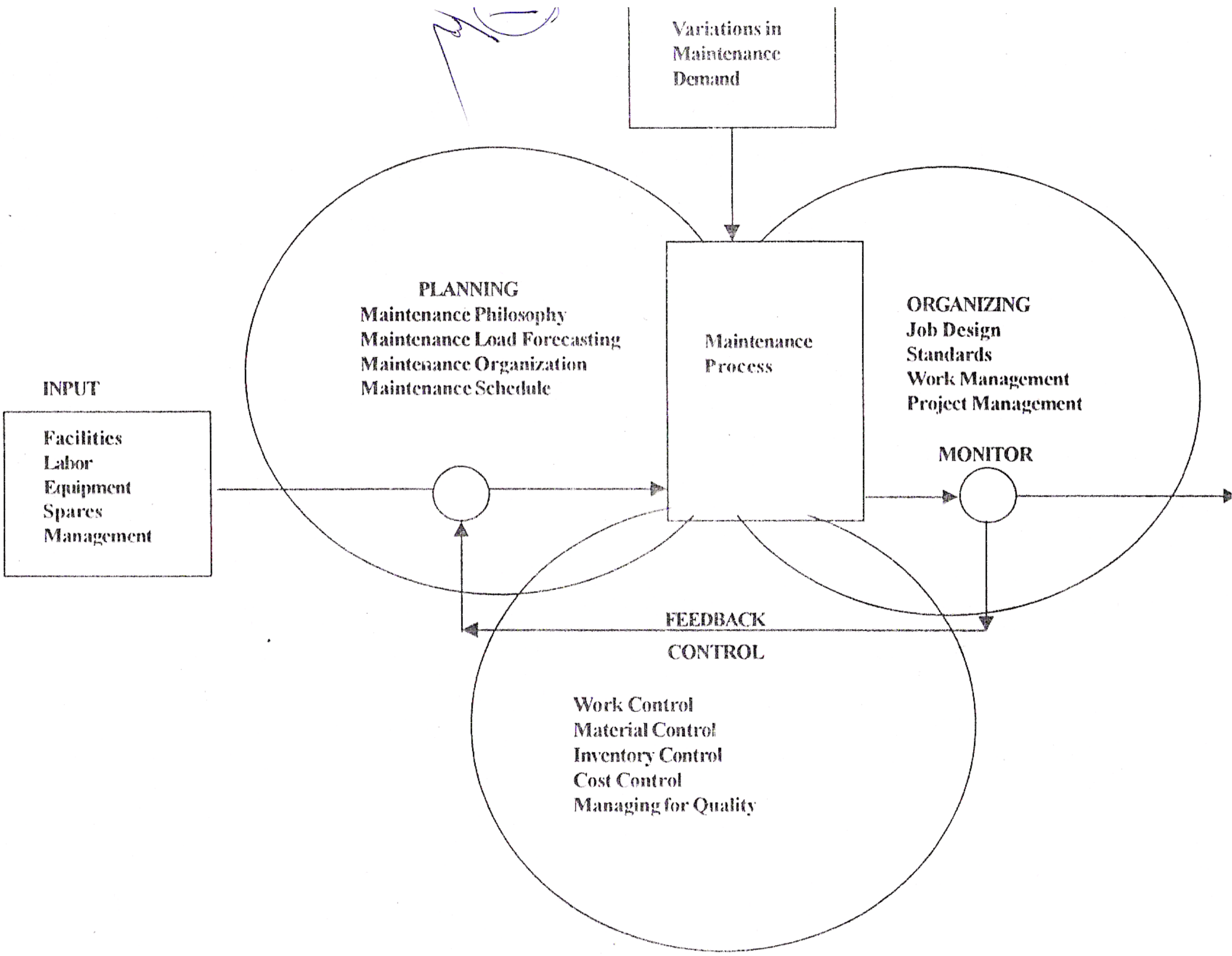


Figure 1.2 : Typical Maintenance Systems

Now, let us break this down into five different elements to understand the process of equipment maintenance:

1. What equipment?

2. What part of the equipment?
3. What maintenance method?
4. Draft a standard maintenance procedure.
5. Carry out systematic maintenance.

1. What Equipment?:

Evaluate the criticality of your equipment based on production, productivity, quality, cost, delivery, safety, and morale criteria based on the evaluation scores, rank the equipment as class AA, A, B and C as per company policy.

2. What Part of the Equipment?:

It is not easy to decide what part of the equipment should be maintained. Logically speaking, during the equipment design and fabrication stages, the critical parts to be maintained should be identified through application of techniques such as FMEA and LTA.

3. What Maintenance Method?:

The maintenance method is usually determined by experience. There is almost no logical or practical methodology that clearly indicates what maintenance method must be applied on what part of the equipment like preventive maintenance, breakdown maintenance and proactive maintenance.

4. Draft the Standard Maintenance Procedure:

The standard maintenance procedure specifies what maintenance method is to be used on what part of the equipment. The 5W1H (What, Where, Why, How, When, Who) principle should be used to draft the maintenance standard.

5. Carry Out Systematic Maintenance:

A necessary tool of maintenance is the maintenance calendar. Other maintenance activities such as spare parts management system are also critical for maintenance application.

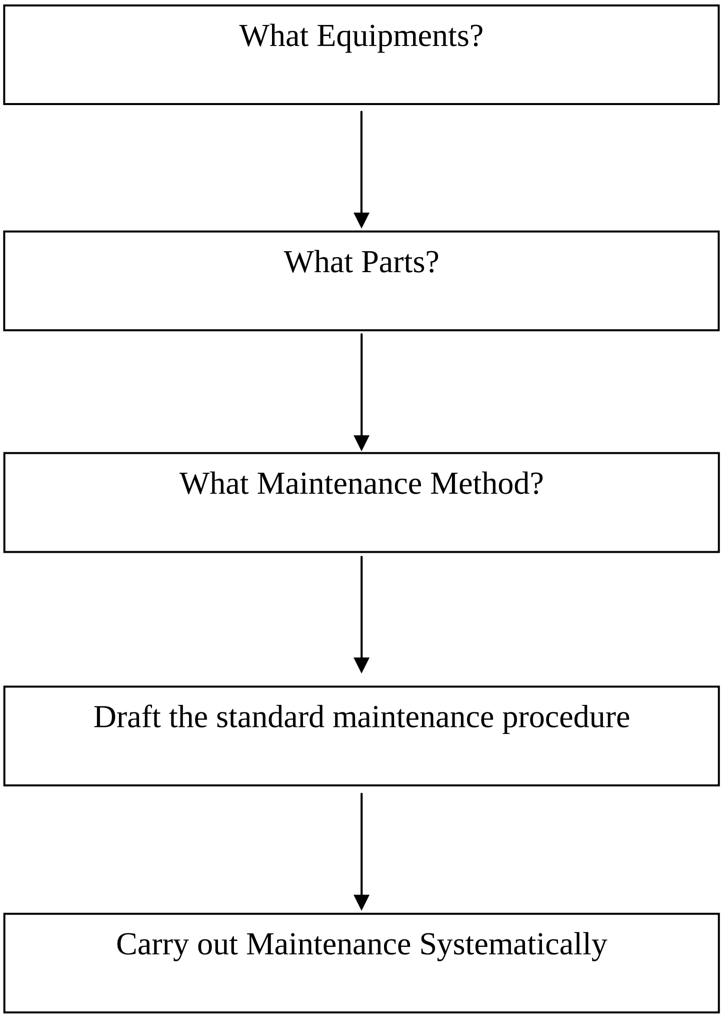


Figure 2.2: The Process of Equipment Maintenance

2.3 BASIC CONCEPT FOR IMPLEMENTING EQUIPMENT MAINTENANCE

The physical analysis of the breakdown is necessary before implementing the equipment maintenance. The breakdown occurs when applied stress exceeds equipment strength. The causes of breakdown can be analyzed as under:

1. **Neglected Deterioration:** Deterioration can weaken equipment to the point where it can no longer endure the stress of operation and subsequently breakdown occurs. The causes of such breakdown can be divided into two groups.
   - The first group includes cases where improper care and poor equipment environment result in accelerated deterioration. In other words, inadequate compliance with basic requirements of the equipment (lack in cleaning, oiling and tightening) causes accelerated deterioration.
   - The second group includes natural deterioration. The deterioration occurs even the proper care and a good working environment. If no restorative measures are taken, breakdown will result.
2. **Uncontrolled Stress:** Even if the equipment has not deteriorated and still retains design strength, breakdown can occur when more stress than anticipated at the design stage is applied to the equipment. Whether intentional or unintentional, if equipment is operated beyond its limit, breakdown will occur.
3. **Insufficient Design Strength:** This is attribute to the equipment designer's inadequate skill or carelessness that causes inherent weakness in some parts of equipment. In this case breakdown can occur under normal stress.

2.4 APPROACH TO ZERO BREAKDOWN

Keeping in view the following factors, the production and maintenance departments can facilitate practical countermeasures. Each of five factors are related to the above three factors of breakdown (neglected deterioration, uncontrolled stress, insufficient design strength), A detailed description of each factor is provided below:

1. **Inadequate Compliance With Basic Requirements :** The operation department does not perform reliably the routine maintenance or lacks a JH system necessary to comply with basic requirements such as cleaning, oiling, tightening and inspection. Neglect of such tasks may aggravate equipment deterioration. Being unable to detect abnormalities caused by stress on equipment leads to inadequate compliance with basic requirements and breakdowns.
2. **Neglect Deterioration:** This is the situation when equipment is still left understood even if it has deteriorated to the extent that it can breakdown at any time. The maintenance and operation departments may lack skill or are incapable of inspecting equipment properly which results in being unable to recognize either invisible or visible deterioration of equipment. This condition allows breakdowns to occur.
3. **Noncompliance With Usage Requirements:** There are generally equipment operating requirements (usage conditions such as compressed air, current, voltage, RPM, velocity, temperature etc) that are specified for equipment to operate at. If usage requirement is violated then stress applied to equipment will exceed the built in stress limits.
4. **Lack of Skill:** Sometimes in equipment restorations, maintenance specialist cannot realize the targeted life span of the equipment. Sometimes breakdowns result from improper repairs. Also, operators may make mistakes because they are not adequately skilled resulting in generation of extreme stress and subsequent equipment breakdown.

5. **Inherent Design Weakness:** Lack of strength can result from design mistakes. These could be careless mistakes or even mistakes attributable to equipment designers or manufacturers, lack of knowledge, experience or information.

2.5 MAINTENANCE PHILOSOPHY

The maintenance philosophy of a plant is basically to maintain a minimum level of maintenance staff that is consistent with the optimization of production and plant availability without compromising safety. The most of the process is composed of a human machine system. The composition is complex and diversified and one operator is incharge of multiple devices, so operator skill may sometimes affect the overall efficiency of equipment.

The automation, unattended operation arrangements, and manpower saving, based on industrial robots, have progressed considerably. The shift to Flexible Manufacturing Systems (FMS) centerd on machinery plants, has gone a long way, allowing unattended operations and increasing equipment, intensive processes in general establishments.

The trend is likely to gain momentum in the future and all responsibilities of production including quality assurance will be concentrated in the field of equipment maintenance. To achieve this philosophy, the following strategies can play an effective role if applied in the right mix and fashion.

2.5.1 PLANNED MAINTENANCE

A planned maintenance system administers the company’s maintenance policy by providing the means of technically and financially directing and controlling the maintenance operations with the objective of higher plant maintenance standards and greater cost effectiveness. The successful planned maintenance system are those, which are simple to administer and involve shop-floor personnel in the minimum amount of paper work. It is characterized by the following:

- The maintenance policy has been stated carefully.
- The application of the policy is planned in advance.
- The work is controlled to conform to the original plan.
- Data are collected, analyzed, and used to provide direction for future. maintenance policies.

The Fig. 2.3 explains the working of planned maintenance management system.

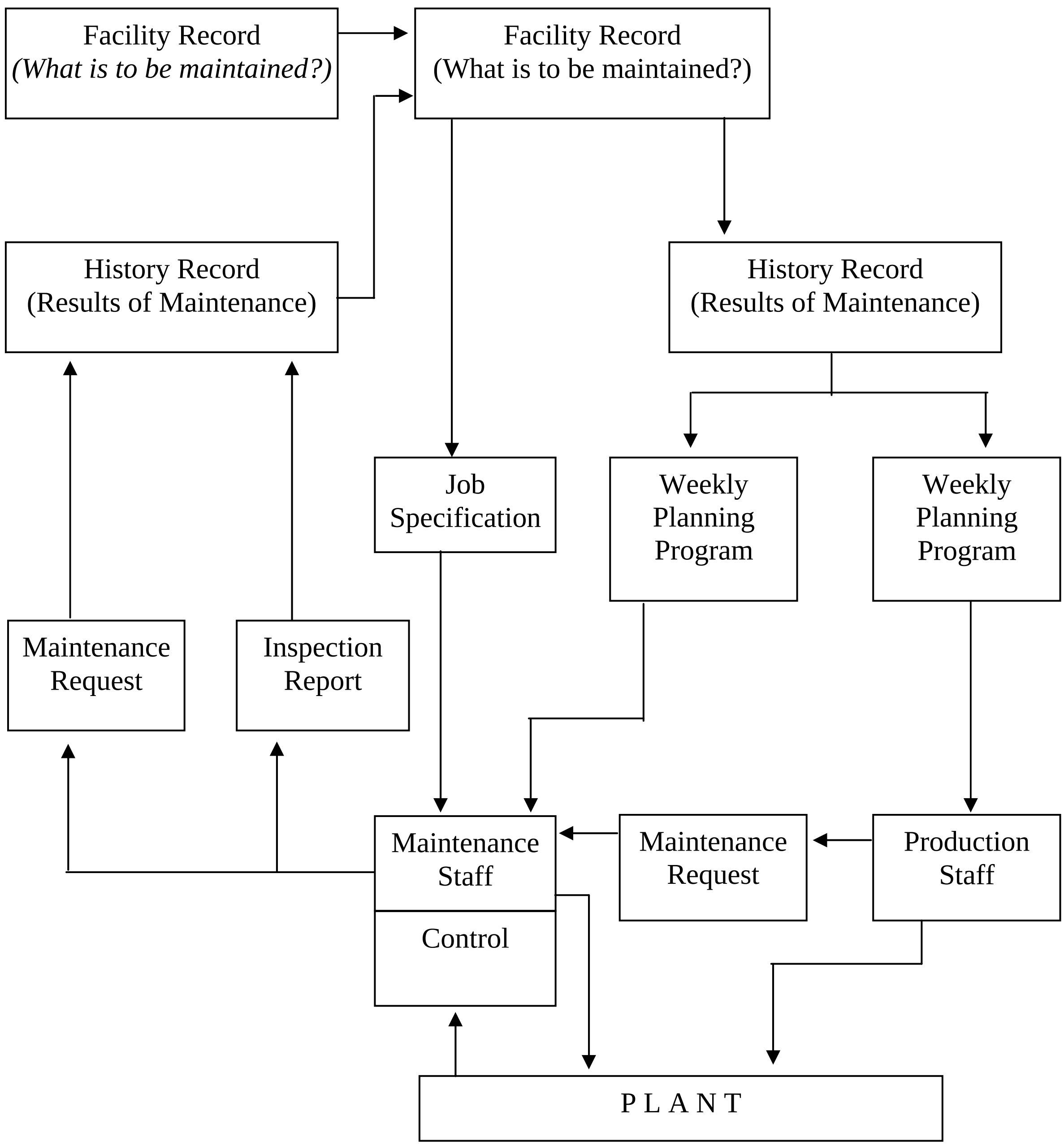


Figure 2.3: Planned Maintenance Management System

2.5.2 PREVENTIVE MAINTENANCE

Maintenance as we have already noted, consists of all work undertaken to keep or restore, every facility that a manufacturing organization possesses, to a specified acceptable condition. Preventive maintenance activities are undertaken because the cost of lost production from unexpected breakdowns is significant, and the cost owning an asset is usually lower when the asset receives proper care during its useful life. Preventive maintenance can be linked to preventive medical science on equipment. It maintains the equipments healthy condition. It is any planned maintenance performed to counteract potential failures. It prevents deterioration by carrying out routine maintenance, periodic inspection, equipment diagnosis, and repairs to restore equipment condition. There are three methods of preventive maintenance as described below:

1. PERIODIC MAINTENANCE

Periodic maintenance, which refers maintenance formula under which maintenance work is, carried out regularly, before the occurrence any failure, entails high maintenance expenditure. Because parts are replaced before they breakdown, however periodic maintenance is inexpensive compared with the breakdown maintenance formula, which may result in costly major failures. Periodic maintenance is a kind of Time Based Maintenance (TBM). TBM is a method under which the deterioration cycle of equipment set in advance, and when the end of the cycle is reached, repair is performed. The decision making is necessary in cases of periodic replacements, periodic inspections requiring the shutdown of the equipment, and periodic overhauls.

2. PREDICTIVE MAINTENANCE

In this type of maintenance, the service lives of important parts are predicted through inspection and diagnosis, and efforts are made to use the parts up to the end of their life, as a result, maintenance expenses and failure losses are minimal this type of maintenance necessitates the development of inspection and diagnosis technologies to predict equipment deterioration through the detection of abnormal symptoms. Predictive maintenance is a kind of Condition Based Maintenance (CBM). Because control of trend values is implemented through measurement and analysis of deterioration data, and because online monitoring system to monitor condition are often operated, it requires higher maintenance technology and maintenance manpower as compared to TBM. Implementing CBM involves measurement or monitoring of appropriate physical variables or signatures of the machine using instrumentation and interpretation the signature to indicate if maintenance of the machine is called for or not. Flow diagram of the condition monitoring procedure is as shown in Fig. 2.4

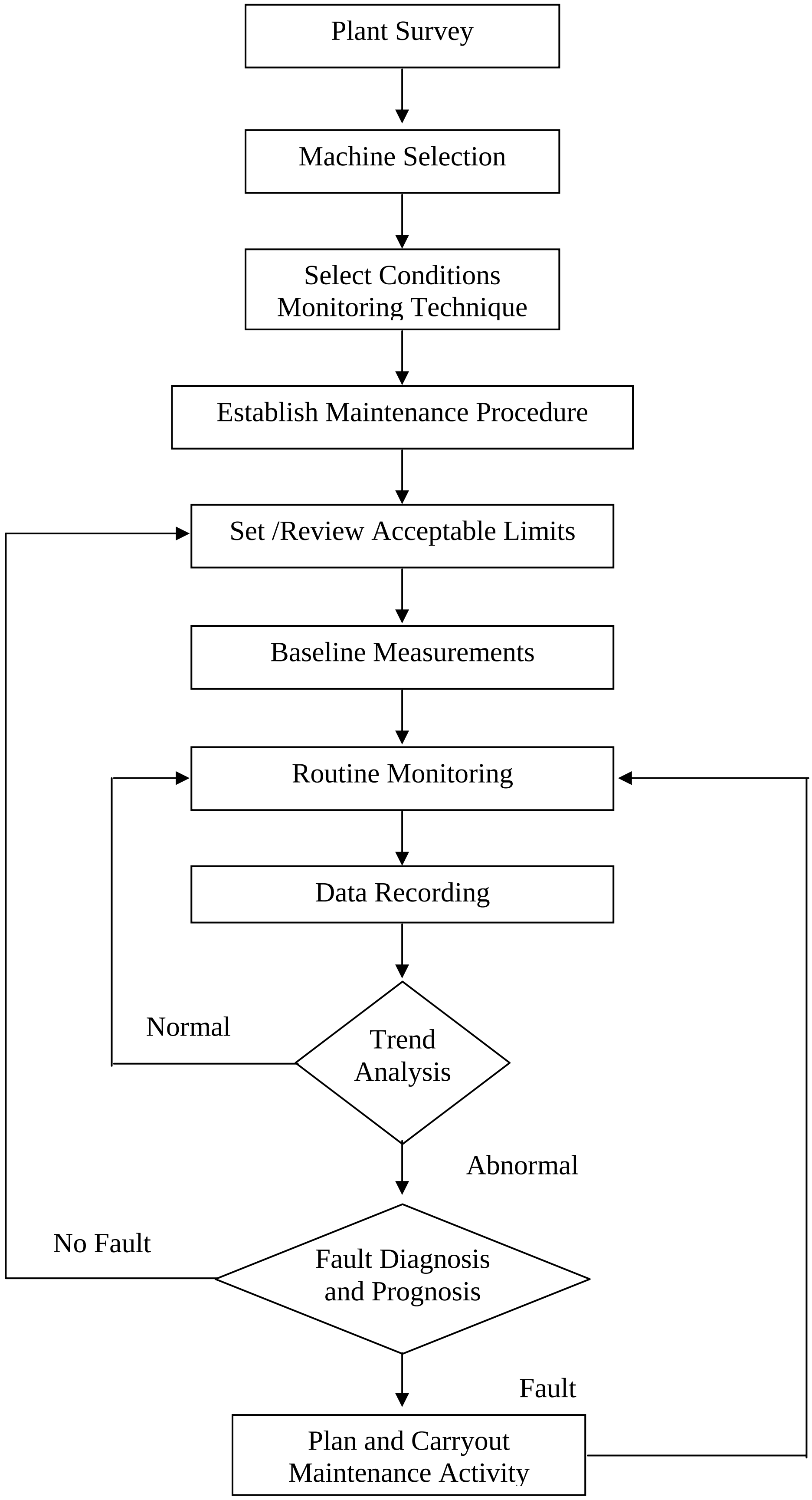


Figure 2.4: Flow Diagram of a Condition Monitoring Procedure

3. OVERHAULING

An overhaul of an equipment, or a system, involves subjecting the equipment and its components to strict inspection, readjustment and calibration or the equipment as required, replacement of worn components and servicing of the equipment, that is, cleaning of its components, greasing and replenishment of consumables such as fuel, lubricating oil, compressed air etc. The overhaul action is taken to restore the equipment to a satisfactory working condition, or as nearly as possible to the ‘as good as new’ condition, to minimize the incidence of unexpected failures, but it is carried out before the equipment, or the systems, reaches a defined failed state. A decision to overhaul an equipment may be taken when the equipment operating and maintenance cost is found to be increasing, or, alternatively, when the equipment hazard rate shows a significant increase but this decision is taken when the equipment is working and not in a failed state.

2.5.3 BREAKDOWN MAINTENANCE

In this type of maintenance the equipment is allowed to run till it breaks down, and then maintaining it and putting back to operation. Here most of the maintenance tasks are reactive to breakdowns or production interruptions and the only focus of these tasks is how quickly the machine or system can be returned to service. The failures may often cause large secondary damages to surrounding machinery before they are discovered.

In breakdown maintenance most of the corrective maintenance work is poorly planned because of the time constraint imposed by production and plant management. As a result, manpower utilization and effective use of maintenance resources are minimal. Breakdown or reactive maintenance may cost three to four times more than the same corrective maintenance work when it is well planned. Another limitation of breakdown maintenance is that it concentrates maintenance work on obvious symptoms of the failure and not on the root cause. As a result, the reliability of the machine or system is severely reduced.

2.5.4 CORRECTIVE MAINTENANCE

This is the maintenance method designed to systematically and positively rectify unsatisfactory sections of existing equipment, in order to improve equipment reliability, maintainability, and safety to reduce deterioration and failures and to seek realization of equipment that does not require maintenance. The word “Corrective” means rectifying equipment that has failed and changing such equipment so that it will not breakdown. Corrective maintenance is limited to those tasks performed in order to restore the machine or system to acceptable operating condition after a failure has occurred. All corrective maintenance tasks are generally accomplished in four steps:

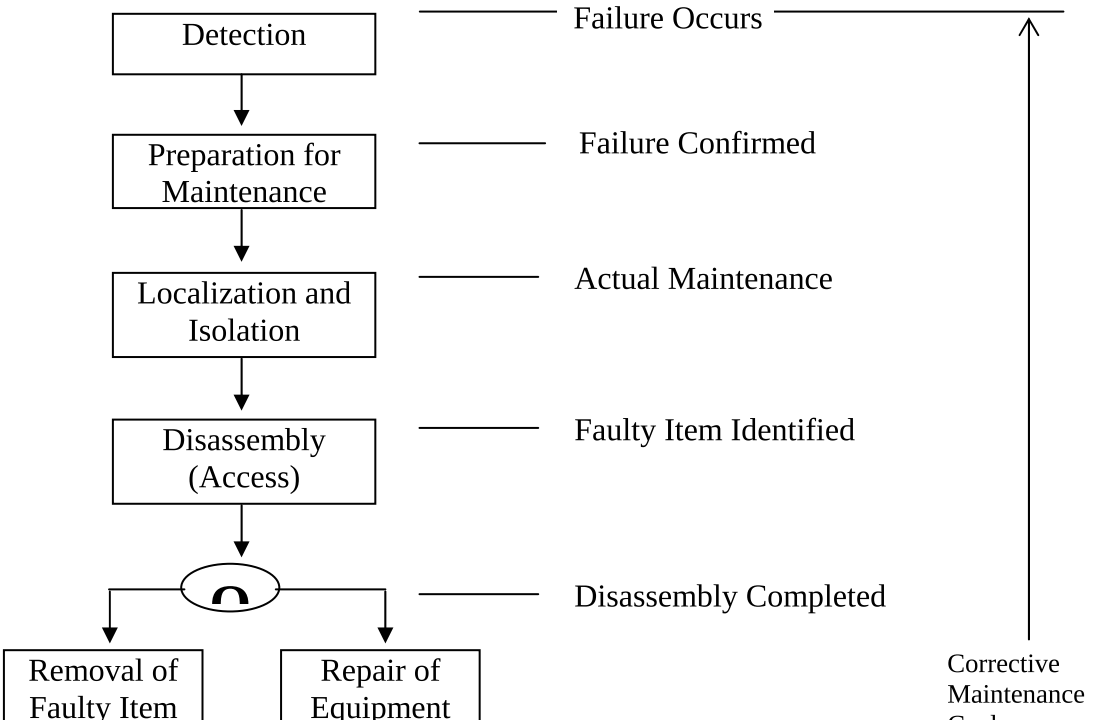
i) Fault detection.

ii) Fault isolation.

iii) Fault elimination.

iv) Verification that the fault has been eliminated.

Fault elimination may be accomplished in any one of the three ways, depending on the nature of the fault. A diagram of corrective maintenance cycle is shown in Fig. 2.5



2.5.5 OPPORTUNISTIC MAINTENANCE

This type of maintenance as the name suggests is carried out when the opportunity arises. Here the decision, to perform maintenance, is taken neither on the basis of condition assessment nor on the basis of elapsed time since the last maintenance, but is carried out in the event of a machine shutdown for maintenance or other reasons (e.g. change of gauge or die). The decision to propone maintenance to the available opportunity is mostly based on the economics of proponing maintenance to that of sticking to scheduled maintenance and going for another downtime.

2.5.6 PROACTIVE MAINTENANCE

Proactive maintenance is receiving much attention as compared to other conventional maintenance strategies. It is based on the maintenance philosophy, which is 'failure proactive' rather than 'failure reactive' and avoids the underlying conditions that lead to machine faults and degradation. Unlike predictive/preventive maintenance, proactive maintenance commissions corrective actions aimed at failure roots causes, not just symptoms. Its central theme is to extend the life of mechanical machinery as opposed to :

- Making repair when often nothing is broken.
- Accommodation failures as routine or normal, or
- Pre empting crises failures maintenance in favour of scheduled failure maintenance.

2.6 TOTAL PRODUCTIVE MAINTENANCE (TPM)

TPM, a unique Japanese system of managerial expertise, was created in 1971, based on the preventive maintenance (PM) or productive maintenance concept introduced from the United States in the 1950s through the 1960s. Subsequently, in the 1970s through the 1980s, TPM gradually developed as its remarkable achievements became recognized. TPM now permeates entire company structures, every line of business, and all parts of the world, this is evidenced by a sharp increase in the number of business establishments receiving PM awards based on TPM, the shift from production-sector TPM to company-wide TPM, and the growing number of countries in which TPM is practiced. TPM was developed by modifying PM with a unique Japanese perspective and tailoring it to the Japanese style of management. TPM is a uniquely Japanese, company-wide plant maintenance method developed in Japan, it is of course based on PM technology and techniques learned from the United States.

2.6.1 DEFINITION OF TPM (COMPANY -WIDE TPM)

1. TPM aims to create a corporate system that maximizes the efficiency of the production system..
2. TPM creates systems for preventing the occurrence of all losses on the front line and is focused on the end product. This includes systems for realizing "zero accidents, zero defects, and zero failures" in the entire life cycle of the production system.
3. TPM is applied in all sectors, including the production, development, and administration departments.
4. TPM is based on the participation of all members, ranging from the top management to frontline employees.
5. TPM achieves zero losses through overlapping small-group activities.

2.6.2 BASIC CONCEPT COMMON TO JIT AND TPM

JIT and TPM are inextricably related. In order to achieve so-called JIT production, which calls for "producing the necessary volume of necessary items at the necessary time," in the present age of progress in atomization it is necessary to reduce sporadic failures, minor stoppages, and defects to zero, and to minimize the setup and adjustment time for the realization of multi-item, small-volume production. TPM can be said to enable the necessary conditions for and to support the complete enforcement of JIT. A look at examples of TPM application reveals that the results of TPM are most remarkable at plants where the JIT production system is adopted. The following five items can be identified as basic concepts common to JIT and TPM:

- Company-wide manufacturing technology directly linked to management.
- Through elimination of waste.
- Prevention of malfunction occurrence in advance.
- On-site (or on the spot), actual goods focus.
- Participatory management and respect for people.

2.6.3 TPM's EFFECTS

At least three years are necessary for the effects of TPM to become apparent. The following examples of TPM effects are given below :

(1) Tangible Effects:

Productivity (P):

Increase in value-added productivity of 150% to 200%

No. of sporadic accident cases cut of 1/10 to 1/250

Overall equipment efficiency improved 150% to 200%

Quality (Q):

Process defect ratio cut to 1/10, customer complaints cut to 1/4

Cost (C):

Manufacturing costs reduced by 30%

Time of Delivery (D):

Product and work-in-process inventories reduction cut by half

Safety / Sanitation / Environment (S)

Case of accidents with interruption of service zero, pollution cases zero

Morale (M):

No. of improvement proposals increased 5 – to 10 fold.

(2) Intangible effects :

a) Through realization of Jishu-Hozen, i.e. people come to preserve their own equipment without being pressed to do so by their superior.

b) The target of zero accidents and zero defects is attained, this makes employees confident in their ability to complete even difficult work, if they resolve to do so.

c) Work sites formerly rife with oil and cutting chips become remarkable clean, helping to create a pleasant work environment.

d) Visitors to plant have a positive impression, which leads to increased orders.

2.6.4 EIGHT PRINCIPLES IN TPM DEVELOPMENT

(1) Establish system to achieve production efficiency:

   a) “Kobetsu-Kaizen”

   b) “Jishu-Hozen”

   c) Planned Maintenance

   d) Education and training for operation and maintenance skill upgrade.

(2) Establish initial production and flow control system for new products and equipment.

(3) Establish a quality maintenance system.

(4) Establish a system to realize operation efficiency in the administration departments.

(5) Establish safety, hygiene, and working environment protection systems.

All the principles of TPM are important, however Jihsu Hozen has major role to minimize the frequency of failures, so more emphasis is given on JH.

2.6.4.b JISHU HOZEN (AUTONOMOUS MAINTENANCE)

Significance of "Jishu Hozen": Jishu Hozen means activities the operator that uses maintenance to personally conduct maintenance activities, including cleaning, oiling, retightening, and inspection, thereby raising production efficiency to its limit. Such activities will prevent forced deterioration of equipment, Thus "Jishu Hozen" represents activities to thoroughly eliminate failures, minor stoppages, defects, and other losses to restore equipment to their desirable forms, maintain them and improve them, and at the same time to develop "personnel that are skillful at equipment operation and improvement".

JH is a self-management activity by small work site groups. Key to the activation of small groups are said to be "morale, skill and places for actions" The prerequisite is creation of the "places for action" promoted as one of the Eight Pillars of TPM development of the entire company / establishment. Through the development of "Jishu Hozen" the operator's willingness and skills increase, so he will be able to "protect his own equipment by himself."

JH brings significant change from early theory of "I manufacturing – You Repair or I Make – You Fix" to "I Make – I Manage" This will lead to "If Equipment Changes - People will Change. If People Change - Shop will Change".

Goal Of Jishu Hozen : The main goal of Jishu Hozen is to develop operators to maintain equipments and work places and follow uniformity in implementing shows floor activities to eliminate forced deterioration on equipment.

Methodology: Jishu Hozen through a step by step methodology describes the approach and activities to be implemented for making the equipment "as it should be." The step by step approach ensure that key skill is thoroughly imparted before going to the next step. The following are the seven steps of Jishu Hozen.

STEP 0: Describes the preparatory work to be carried out before initiating JH activity on the equipment.

JH development leads to autonomous diagnosis of the equipment performed by a team under the leadership of supervisor based on the processes in order to increase the level of equipment and operators performance. The supervisor has to give details related to safety function of the equipment and mechanism to team members. All those involved in the team need to known what is the meaning of "abnormality" dirty, loose, hanging, leaking, splashing, broken, excess length, heat, vibration, corrosion unwanted, missing, worn out, abnormal noise etc.

STEP 1 : CONDUCT INITIAL CLEANING AND INSPECTION

Operators develop an interest and concern for their equipment through cleaning them, thoroughly cleaning and inspection marks the crucial start of the JH activities.

There are three main things to remember about cleaning and inspecting:

- Cleaning is inspection.
- Inspection means finding problems.
- Problem lead to either restoration or improvement.

Cleaning doesn't mean polishing the outside of equipment or its electrical panels. The equipment should be taken off line covers and guards removed, oil tank drained and manually clean every hook or corner of the equipment which was never touched before. Cleaning helps to find what is wrong with equipment sometimes cleaning also reveals big surprises, such as a cracked frame that had been masked by accumulated dust, a lubrication inlet hidden by dirt or switches covered with grime so that they no longer function correctly.

STEP 2: ELIMINATE PROBLEM SOURCES AND INACCESSIBLE AREAS

This step is intended to carry out the following activities:

- To eliminate sources generating dust, dirt, and stains.
- To improve places where splashing are existing.
- To improve places that are hard to access for cleaning, lubricating retightening and inspecting.

The team begins with a goal of stopping problems at sources. For example, machining operation continuously produces chips or when a stream of coolant scatters chips. During these kinds of situations, the team should minimize the scattering by installing localized covers. When making improvements the following points should be keep in mind:

- Make the equipment easier to clean.
- Minimize the spread of dirt, dust and oil.
- Stop contamination at its source.
- Minimize the scattering of cutting oil and chips.
- Make the equipment easier to inspect.
- Install inspection windows in the equipment.
- Tighten loose areas in the equipment.
- Make it easier to replace equipment parts.

STEP 3: DEVELOP TENTATIVE STANDARDS FOR CLEANING, INSPECTION AND LUBRICATION

With the experience gained, the operators determine the optimal conditions for cleaning, lubrication and inspection for the equipment. They draft the preliminary work standards with the help of their manager and maintenance to maintain the conditions of the equipment. Work standards specify what needs to be done, where, why, how and when. The team decides which parts of the equipment need cleaning and how often, which method to use, what to inspect while cleaning, how to judge whether conditions are normal and so on. The standards are more likely to be followed when these three criteria are observed:

- The people doing the cleaning and lubricating understand the importance of these tasks.
- The equipment is improved to make cleaning, inspection and lubrication easier.
- The time required for cleaning and lubrication is included in the daily schedule.

Operators must measure the time required for each task and the ways to eliminate/minimize the time consumed for Cleaning, Lubrication, Retightening and Inspection (CLRI). This can be accomplished by investigating innovative ideas, such as visual controls. Some, ideas for visual control are:

Lubrication:

- Colour-coded marks to indicate oil inlets.
- Indication of upper and lower level limits.
- Indication of oil consumption per standard time limit.
- Colour-coding on oilcans to indicate oil types.

Pneumatics:

- Pneumatics pressure gauge limits oil level display.
- Display of upper and lower oil level unit.
- Tube connection marks (inlet, outlet).
- Tube connection marks (inlet, outlet) color code.
- Colour coded supply lines.
- Flow directions (arrows).

Drive Systems :

- Indicate V-belt/ chain type.
- Indicate V-belt/ chain direction of rotation.

- Install peep windows for checking belts.

In order to strictly observe and preserve the equipment conditions, the following details are to be imparted to operators:

- Clarify what and how it should be observed.
- Explain to the operators what would happen if it was not observed. Let them "know-why". Develop enough skill for the operators to observe the criteria.
- Allocate time for observing the criteria.

It is necessary that parameters to be observed on the equipments be prepared by the operators, themselves. This is the first step towards autonomous maintenance.

STEP 4: CONDUCT GENERAL INSPECTION, TRAINING AND DEVELOP INSPECTION PROCEDURES

To impart the technical knowledge to operators the JH sub committee/TPM secretariat needs to identify the various technical subjects in consultation with operation and maintenance division. Generally the following technical subjects are covered:

- Hydraulics
- Pneumatics
- Drives
- Lubrication
- Coolant
- Bolts & Nuts
- Electrical

The JH sub committee / TPM secretariat need to prepare text in the local languages on the technical subjects identified for operators with flow charts, diagrams, photographs illustrating good and bad components. After preparing texts, they need setup 'Technical Training Centre". Where models and cut models of sub assemblies used for seeing and understanding. The key activities in step 4 are as follows:

- Learning the structure, functions and mechanism of the equipment.
- Test the understanding and then actually inspect the equipment.
- Correct new problems found.
- Produce excellent results.

STEP 5: CONDUCT GENERAL INSPECTIONS AUTONOMOUSLY

In this step, an overall inspection process is formalized by combining tentative standard created in step 3 with the additional check items for routine inspection. All inspection items for each area of equipment are split into two lots. One is, items that can be handle using autonomous inspection and the other is, items that requiring inspection by maintenance. If any breakdown occurred, operator has to work with the maintenance to develop inspection points that will prevent the breakdowns from happening again. Incorporate these new inspection points into standards. At this stage the activities are as follows:

- Review the items, method and time standards for cleaning, inspection and lubrication.
- Consult with maintenance division about inspection points and make specific and clear assignments between two.
- Check whether or not the inspection tasks can be done within scheduled time and make time saving improvements.

It is necessary to clarify inspection item sharing with maintenance division. Some of the inspection criteria are common between autonomous inspection followed by operators and optimal condition check sheet, maintenance standards etc. followed by maintenance. The operator should preferably be incharge of some of the criteria specific to equipment. The co-ordination between operation division and maintenance division is very much important in selection of inspection items. At this stage, combination of specialized maintenance activities and autonomous maintenance activities will create the most efficient overall system.

STEP 6: SET STANDARDS AND MANAGE THE WORK PLACE

The sixth step of autonomous maintenance is often called maintenance management. This means "standardization a operators activities" From step 1 to step 5 the focus of the operator was doing CLRI and maintaining basic conditions of equipment after thorough understanding of equipment. In step 6, operators need to go beyond equipment to other aspects related to his operation. Using principles of good house keeping and visual control the surroundings of equipment is to be changed. Establish standard quantities and locations for the essential elements required for operation.

These organizing and standardizing activities are emphasizing the following points:

- Decide when, by whom and how each item should be used.
- Check the quality and quantity of items so that they can be used to full advantages.
- Arrange items so that people can see at a glance where things are and how they should be used.
- Decided how to arrange all required items and determine what quantity is required according to their frequency of use.
- Store items in such a way that they occupy little space as possible and can be easily moved.

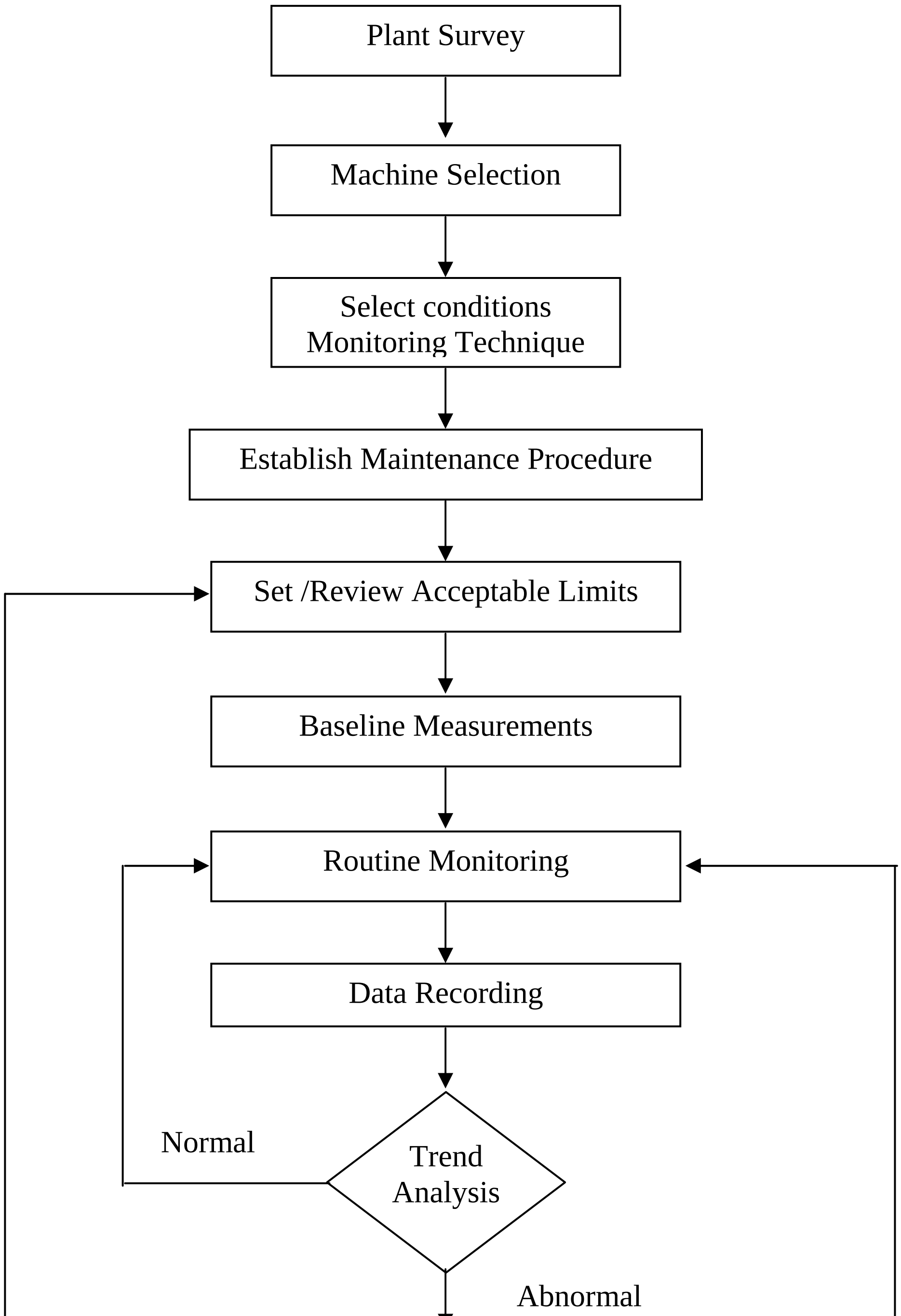
Decide who is responsible for every day management tasks and how materials, parts or tools will be supplied. These activities link the goals of equipment management and production management and promote transparency in the work place.

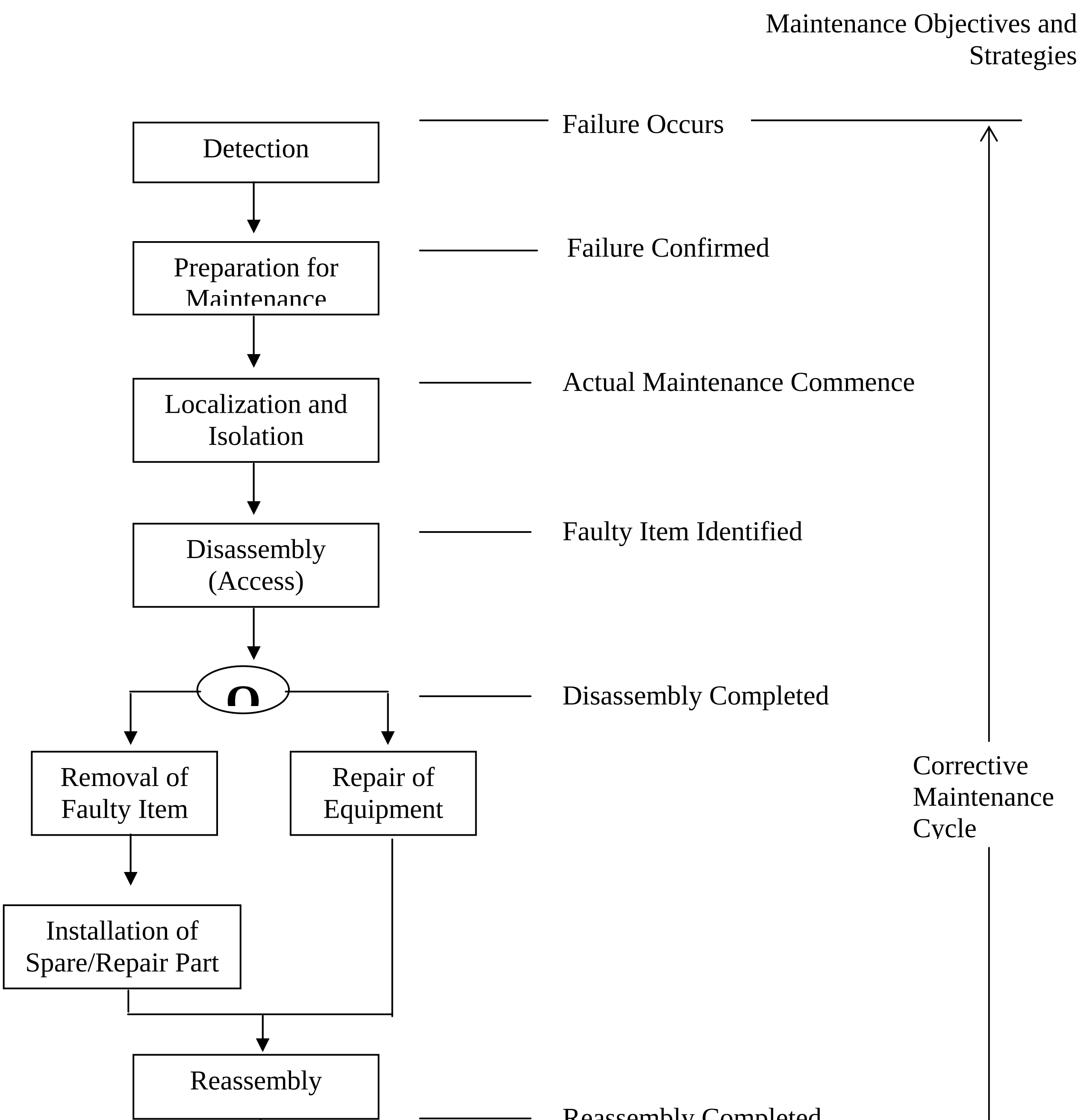
STEP 7: ONGOING AUTONOMOUS MAINTENANCE AND ADVANCED IMPROVEMENT ACTIVITIES

In the implementation of JH step 1 to step 6, each step emphasized different developmental activities and goals. Each stage develops thorough understanding and brings results such as equipment change, operators change and workplace change. In respect of operators the following skills have been acquired:

- The ability to detect, correct and prevent equipment abnormalities and make improvements.
- The ability to detect causes of abnormalities.
- The ability to understand the relationship between equipment and quality.
- The ability to predict problems in quality and detect their causes.

The concept of JH having all steps is shown in the Fig. 2.6




Maintenance Objectives and Strategies
Detection
Failure Occurs
Preparation for Maintenance
Failure Confirmed
Localization and Isolation
Actual Maintenance Commence
Disassembly (Access)
Faulty Item Identified
Disassembly Completed
Removal of Faulty Item
Repair of Equipment
Corrective Maintenance Cycle
Installation of Spare/Repair Part
Reassembly
Reassembly Completed

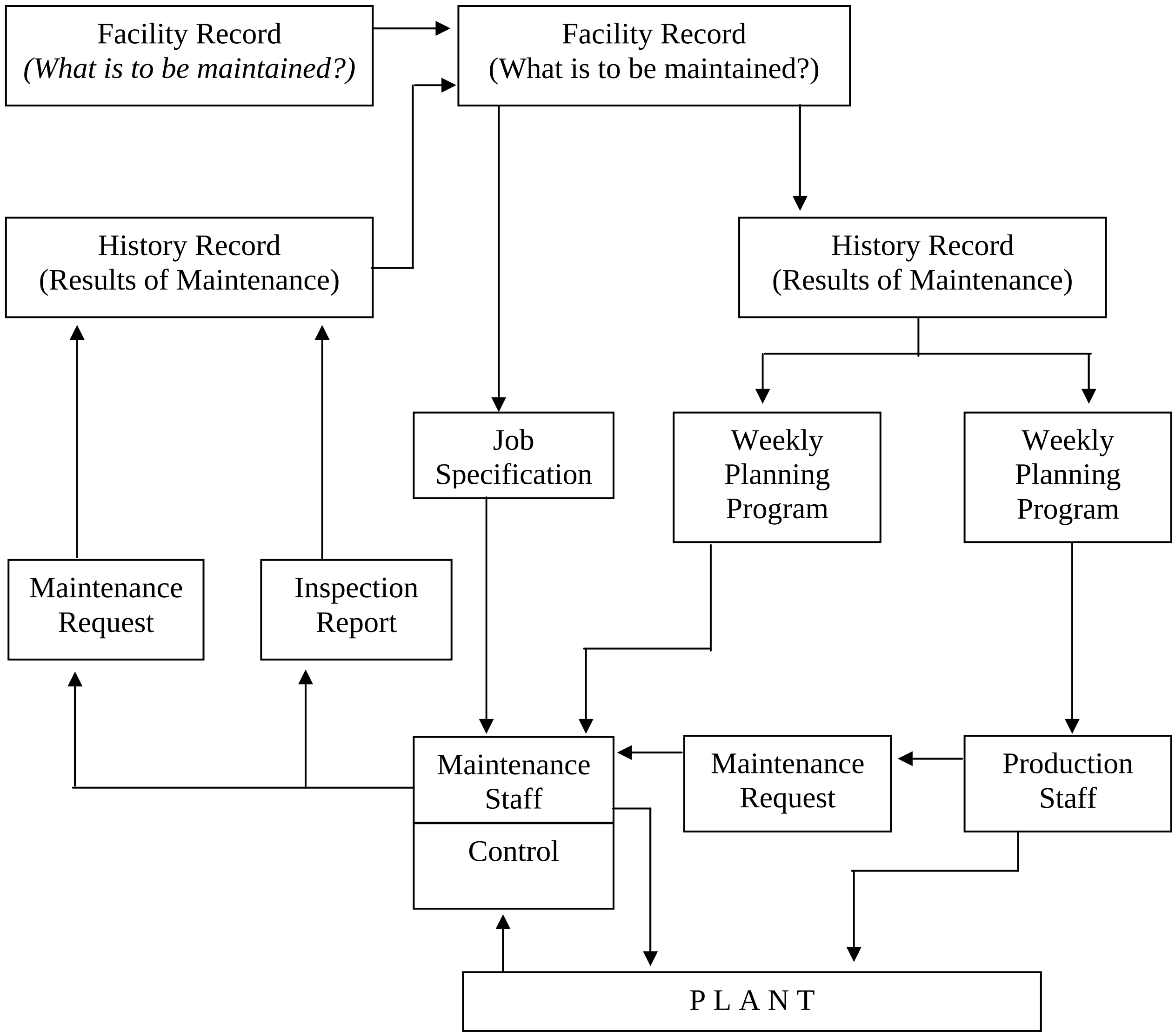


Figure : Planned Maintenance Management System

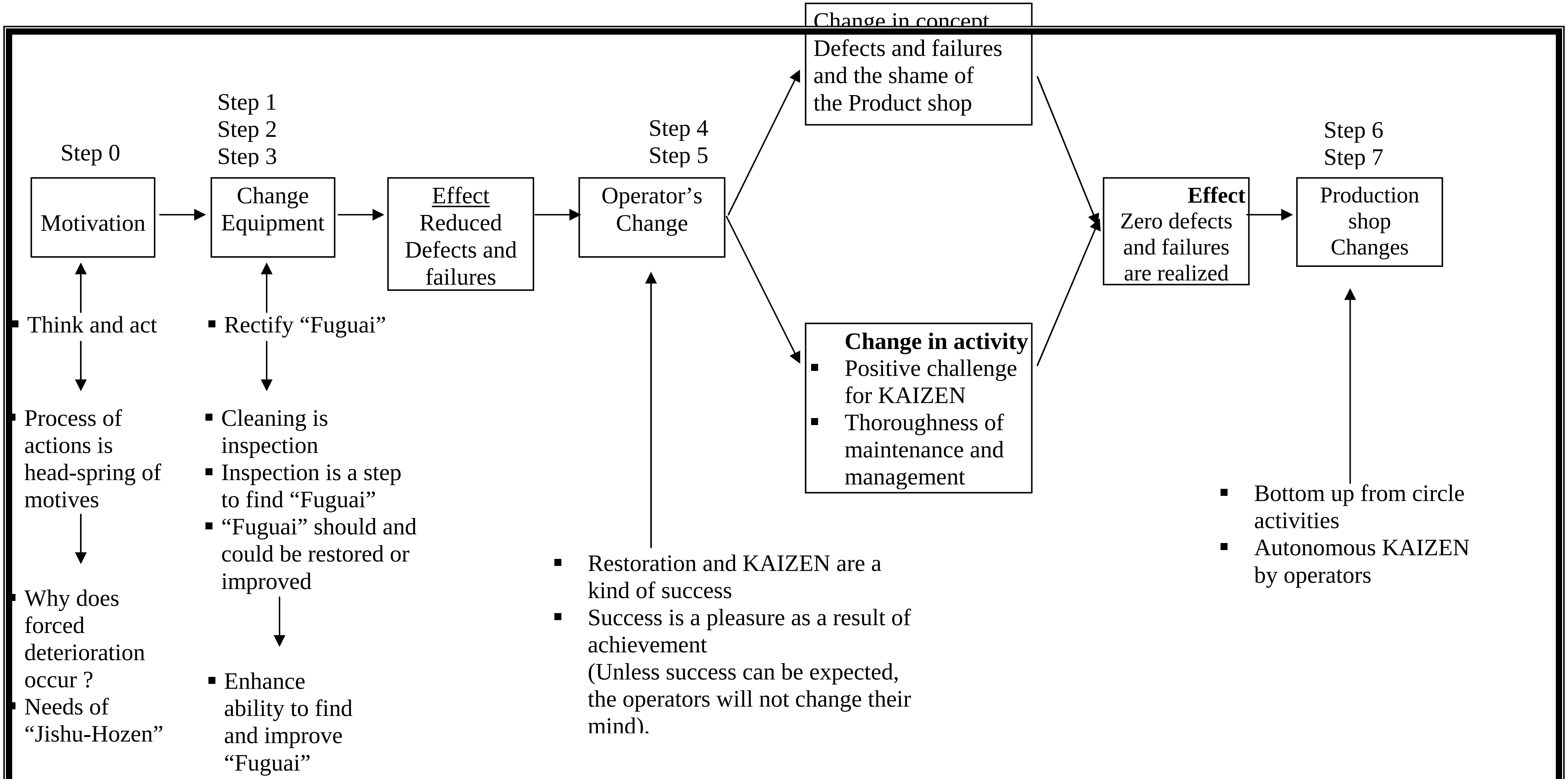


Figure 2.6 : Concept of Jishu Hozen

2.7 CONCEPT OF REENGINEERING MAINTENANCE

Reengineering is the reaction to increasing competition and the new opportunities offered by technology. Reengineering is possible because technology has changed the business of business. But no matter how much business and other organization reengineer, roofs, pavement and equipment still deteriorate. Good maintenance practices, whether they are lubricating a bearing or doing complete infrared scan of the buss duct, are still needed. In reengineering it is less focused on what maintenance practices are chosen and more focused on how the jobs will initiated, who does them, what support is provided and who else is floating around. The difference between continuous improvement and process reengineering is summed up by Peter Drucker. "There is nothing less useful than to do a little better that which should not be done at all" In reengineering look at the process of delivering maintenance and decide if task should be done at all.

After the tasks are shaken out, it can apply continuous improvement to improve the tasks that are left. The first rule of reengineering is to look at the process that maintenance is part of, instead of the department or function of maintenance. Reengineering starts with the customer's needs and works through the process of delivering satisfaction. It focuses on the hand offs between departments and the idle time versus work time. Many companies have gone through complete reengineering. Reengineering is a billion-dollar business. The biggest management-consulting firms have major department in reengineering the whole business one process at a time. In some cases the experience of engineering in maintenance is not a positive one.

2.8 COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEMS

A computerized maintenance management systems (CMMS) is basically an information system adapted to serve maintenance. A CMMS aids in the process of data collection, recording, storing, updating, processing, communicating, and forecasting. It is essential for planning, scheduling, and controlling the maintenance activities. Through effective reporting, a CMMS can provide maintenance managers and engineers with the information needed for sound decision making to control and improve the maintenance process.

Computerized system is used to lower or avoid costs, improve service, control costs, ensure uptime, improve quality etc. The computer allows us easier access to masses of data and to levels of analysis not readily available manually. The computer also has the capability to perform tasks too time consuming for people. This enhances the ability of a lean maintenance department to have top quality analysis. The latest hardware/software has capabilities that cannot be duplicated manually with any number of people such as real time monitoring. The latest systems now can have an impact on the shop floor while the repair is in process. There is tremendous excitement in the field because the threshold automation of existing manual system have passed. The decision to computerize is actually a surface decision for a much deeper decision. A decision to computerize is also a decision to treat maintenance as a serious profession. The decision to computerize is also a decision to impose discipline on a group of mechanics. The computer is a tool that maintenance managers imagine, will allow them to predict, affect, analyze, and eventually control what goes on in maintenance. The reason that most CMMS installations go astray and never realize their promise is because the firms though that they were only computerizing, and only asked hardware, software and database type questions. They never asked themselves the deeper questions of what they are about, how do they view maintenance, and what is their role in future incarnations of the organization . Computerization of maintenance is a complex job when measured against other computerization efforts. The reason is so complex in the nature of the data collected. In terms of support to the maintenance process, a CMMS usually includes the following functions:

- Equipment identification and bill of material.
- Preventive maintenance.
- Work order management.
- Planning and scheduling.
- Inventory control and purchasing.
- Labor and job standards.
- Equipment history.
- Costs and budgets.
- Performance reports.
- Quality reports.

In the design process of CMMS, one or more of the preceding functions are usually grouped into one module. To support the previous functions CMMS consist the following five modules:

1. Equipment management.
2. Work order control.
3. Crafts management.
4. Material supply and control.
5. Performance reporting.

The foundation of CMMS is shown below.

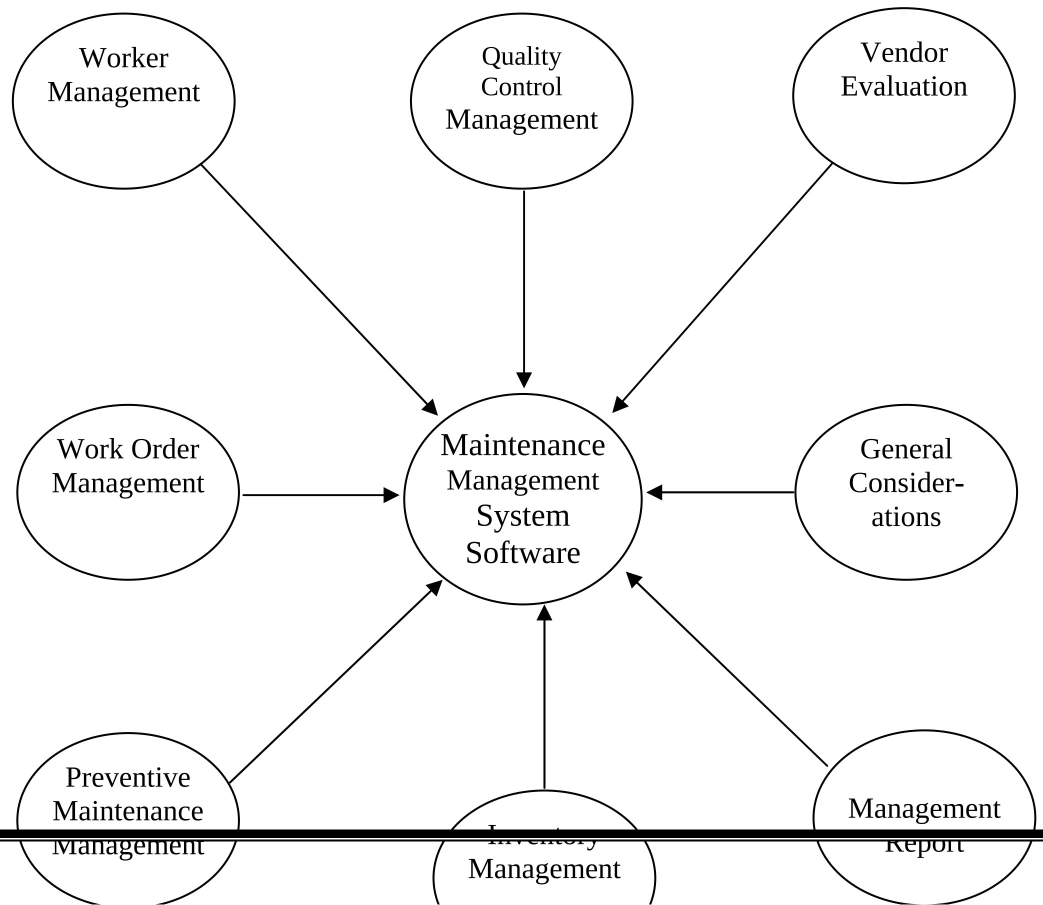


Fig. 2.7 : Foundation of computerized maintenance management systems

2.8.1 BASIC COMPONENTS OF CMMS

The figure 2.8 highlights the basic components of CMMS. Work order is the key feature of the system. It consists all of the labour data, materials data, contractor data, preventive maintenance data that is written against a piece of equipment. The information collected is then stored in a database called the equipment history. It is here that all of the data is drawn to reproduce all of the reports needed by the organization to manage the equipment or assets. The CMMS most basic function is to organize all equipment information into a workable database.

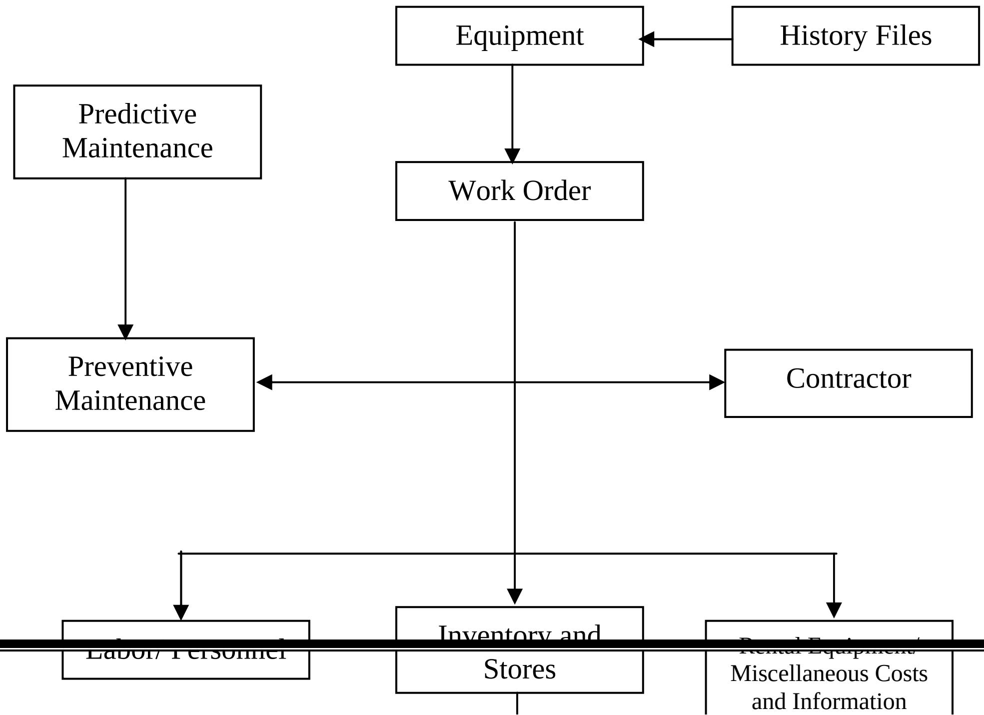


Fig. 2.8: Basic function of CMMS.

2.8.2 BENEFITS OF CMMS

Implementation of a CMMS is most successful in organizations that have committed to a long-term maintenance strategic master plan based on the result of a benchmark assessment of current maintenance practices and procedures. A CMMS provides the system tools and the information framework to integrate best practices into the maintenance process, and to lead and manage maintenance as a key part of the total operation. The effective use of a CMMS is an integral tool for achieving a world-class maintenance. Crafts people and maintenance leaders must work as a team with operators and operations leaders if significant improvements are to be made in the total operations process. The benefits of CMMS are listed below:

- Improved work control.
- Improved planning and scheduling.
- Enhanced preventive and predictive maintenance (PM/PdM).
- Improved parts availability.
- Reduced storeroom inventory.
- Improved reliability analysis.
- Increased budget accountability.
- Increased capability to measure performance.
- Increased level of maintenance information.
- Statistically determine when equipment will fail using performance analysis.
- View graphical representations of a complex piece of equipment and its component parts family tree.
- Keep records for use in ISO and other industrial certifications.

- Generate backlog reports of corrective and preventive maintenance tasks. Hide confidential information from users who do not need to access such data.
- Print visual maintenance information.
- Evaluate outside vendor performance by tracking on -time delivery records.
- Track and generate employee-training histories.
- Prepare for equipment shutdowns.
- Track expiration dates of vendor service contracts.

2.9 MAINTENANCE TRAINING

Maintenance activity is considered to be a function inclusive of the actions necessary for keeping equipment and facilities performing at desired levels. Among all the factors necessary, maintenance-training programs are the most important. It is imperative that maintenance personnel acquire the requisite technology and skills that will enable them to realize their full potential.

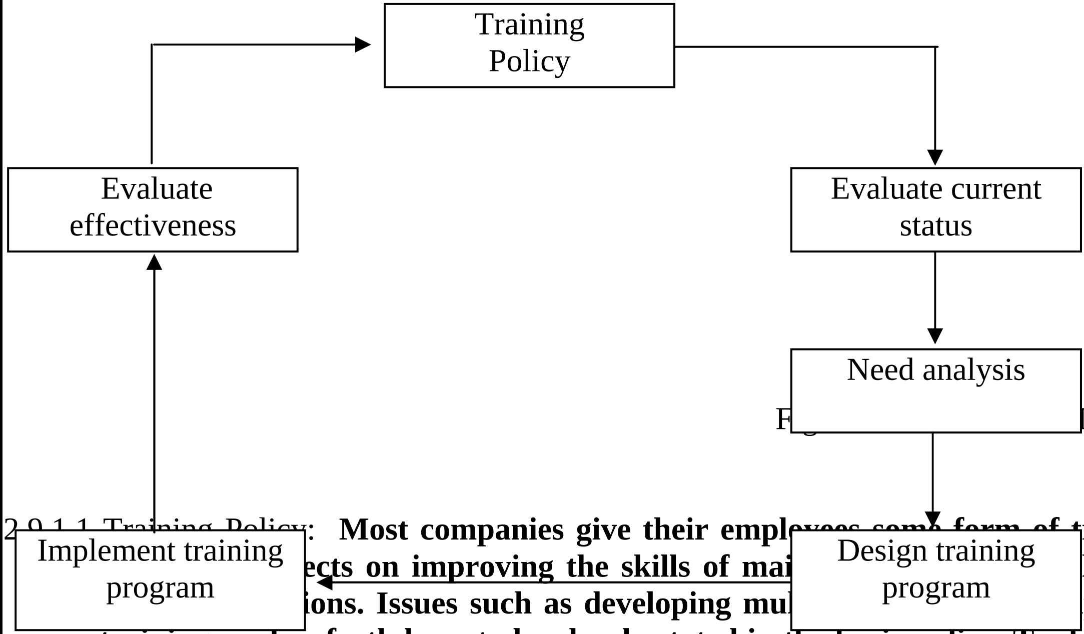
Maintenance workers are traditionally craft oriented and have more freedom of action than production workers. They require extensive training and experience to be fully qualified. The fact that maintenance is dynamic, in that, new deficiencies in equipment are continually arising while old problems are in the process of being corrected, coupled with the fact that new equipment based on the latest technology is being introduced by industry, makes it imperative that the maintenance worker's training be planned, carried out, and evaluated.

Efforts are made to assign the right workers to different functions so that each worker is fully conversant with his/her functions. In fact, the workers available are never entirely qualified, often due to a lack of formal training. Production work is routine and, as such, requires less information to be processed than maintenance work. Maintenance work presents different levels of information processing and decision-making. The performance of maintenance workers can be improved through a combination of motivation and training. It is necessary to identify the existing skill levels of the workers before a training program can be implemented. There are four levels of skills:

Level 1. Person lacks theoretical knowledge and practical ability.
Level 2. Person is conversant with theory but lacks practical training.
Level 3. Person possesses practical experience but lacks theoretical concepts.
Level 4. Person is adequately conversant with theoretical aspects and has practical competency.

A good training program should be custom-designed to fit the various skill levels. To make training effective, due care must be exercised in scheduling the appropriate training at the right time.

Maintenance activities can be considered in the form of a cycle as shown in the figure 2.9



F… Training Activities.

2.9.1.1 Training Policy: **Most companies give their employees some form of training. The existing training program must be reviewed periodically to** …**ects on improving the skills of mai**… **he focus should be on developing a training program that improves the** …**ions. Issues such as developing mul**… **parting specialist skills through a combination of lecture and on-the-job training, and so forth have to be clearly stated in the basic policy. To develop equipment-competent maintenance workers and to nurture human resources that will meet long term requirements should be stated explicitly in the company's goals.**

2.9.1.2 Evaluating Current Status: **More sophisticated and automated equipment has increased the need to ensure quality of output, low energy consumption, and safety of operation. A well-designed training system is essential in order to meet these objectives. Usually, maintenance professionals should be able to perform the following activities:**

- **To asses if the equipment is operating normally.**
- **To diagnose the causes of abnormalities and restore normal operations.**
- **To improve equipment reliability and minimize abnormalities and failures.**
- **To minimize the related costs.**
- **To perform the job with the required level of quality and safety.**

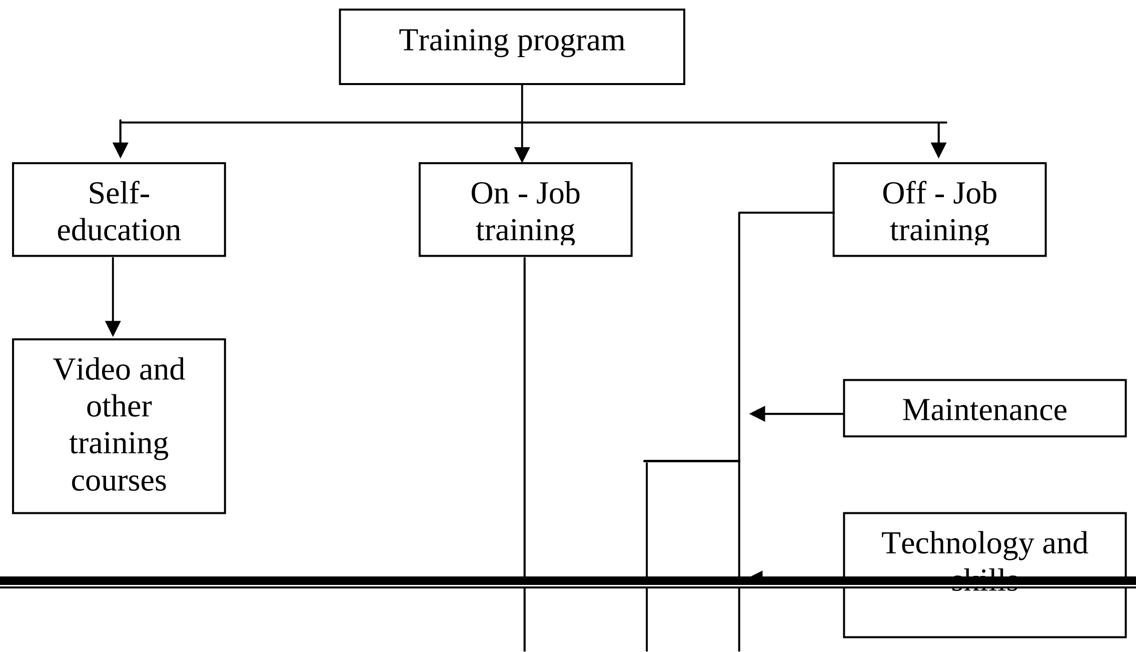
2.9.1.3 Need Analysis: It is essential that a worker possess the necessary skills for performing a given task but it is not sufficient to perform the tasks adequately.

Factors like motivation, availability of necessary tools, and so on are known to affect worker performance.

A need analysis is carried out to identify worker performance deficiencies, to pinpoint the causes of these deficiencies, and to determine the appropriate solutions. This process is normally based on the following five steps:

- Identifying the desired performance.
- Identifying the deviations between expected and actual performance.
- Identifying the root causes of the deficiencies.
- Identifying appropriate solutions.
- Selecting and implementing the appropriate solutions.

2.9.1.4 Designing the Training Program: Currently, the use of robots, numerical control machines, and flexible manufacturing systems by industry is increasing every day. Maintenance of this sophisticated equipment posses a challenge to the maintenance group and also increases the demand for multiskilled personnel. Engineers and technicians, in addition to maintenance workers, must also be trained. It is desirable that a company develop equipment competency at every level. To develop such competency, a program of training must be constructed that progresses in steps from elementary through basic, intermediate, and advanced skills. An outline of a training program is shown in figure 2.10



2.9.1.5 Implementation of the Training Program: A training curriculum has to be developed, while developing such a curriculum, due consideration must be given to the equipment that the company has, skill levels required for maintaining it, and what specific items to teach and how much time should be spent in teaching these items. A typical maintenance training system may include courses and on-the-job training shown in Fig. 2.11

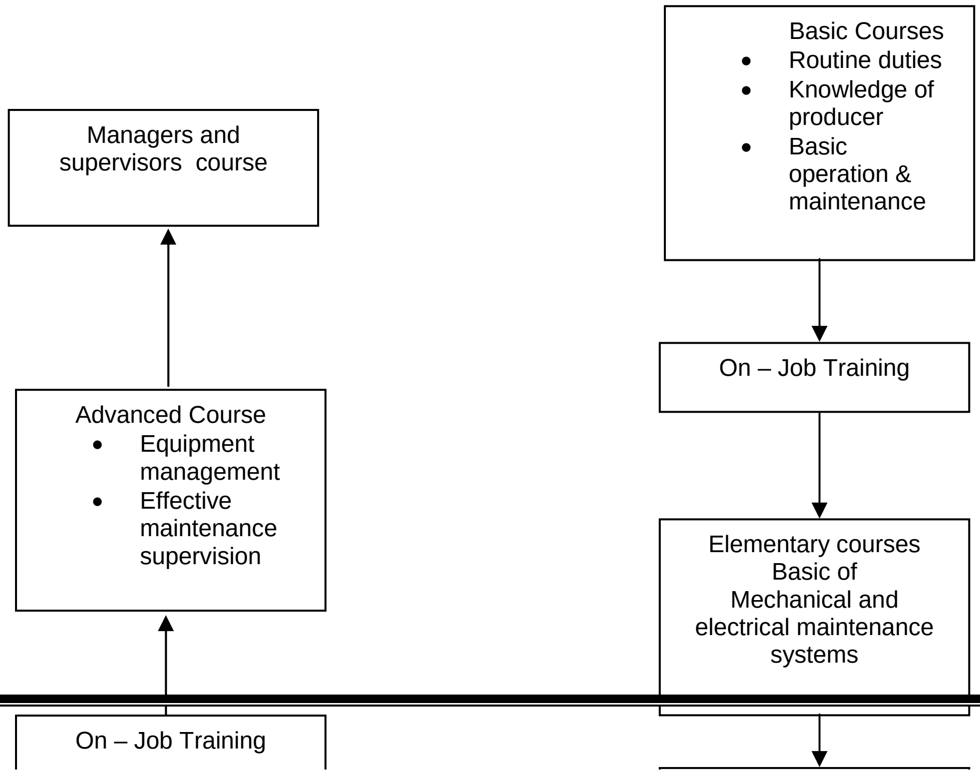


Figure 2.11: Typical maintenance training system

2.9.1.6 Evaluating Effectiveness: The effectiveness of any training program should be evaluated periodically. During this evaluation, the progress made by individuals toward skill development should be observed. Periodic reviews of the skills, training system, training processes, and the curriculum are essential ingredients for continuous improvement. For this purpose, a worker-skill inventory form can be used. This form provides the information regarding additional skills needed by each worker and also the total additional skills for all the workers with respect to maintaining a particular equipment. The data obtained before the onset of a training program may be compared with the date collected after completion of the program. Rates of progress may be examined to see if the target has been achieved. This may necessitate looking at the entire program in case the desired target is not achieved. Similarly, rates of rework by each worker before training and after training will give some insight into the effectiveness of the training program.

CHAPTER 3: RELIABILITY CENTERED MAINTENANCE METHODOLOGY

3.1 INTRODUCTION

In modern environments with Just In Time (JIT) philosophies and reduced buffer stocks, maintenance is expected to deliver increased performance in terms of efficiency, reliability and plant availability while simultaneously minimizing its impact on production and keeping costs as low as practicable. During the last five decades technical innovations have brought the dream products into reality as well as the production volume has been considerably increased. In the initial phase of this development, product development and manufacturing engineering have been the dominant and significant technical disciplines, whereas Operation and Maintenance (O&M) was given secondary treatment. With the adoption of modern sophisticated machinery, methodologies, expenses/costs incurred on product development and manufacturing engineering are almost at par for similar type of industry with same scale. Therefore O&M offers an opportunity for cost reduction. It also plays a significant role in various issues such as safety and environmental factors.

In most of the cases, the traditional view of maintenance is based on belief that all failures are bad and must be prevented. However, this is practically unrealistic from two angles. Firstly, from purely technical point of view, it is often not feasible to prevent failure. Secondly, even if one could prevent or anticipate all failures it would be cost prohibitive. Hence, it is necessary to have a framework, which can reduce the routine maintenance tasks to sustainable minimum without affecting the plant performance, product quality, safety or environmental integrity. Reliability Centered Maintenance (RCM) provides a network, which enables the users to respond the challenges quickly and simply.

The Concept of Reliability Centered Maintenance (RCM) originated within aircraft industry and later adapted and applied by nuclear power industry, offshore oil and gas industry and military branches. RCM is a method for maintenance planning and can be defined as a systematic consideration of the function of a system, the way a function can fail and priority based consideration of safety and economic aspects that can be used to establish an effective maintenance tasks and schedules. The main focus of RCM is therefore on the system functions and not on system hardware. It is based on the principle that the inherent reliability of equipment is a function of their design and builds quality, and hence an effective maintenance will ensure that the inherent design reliability of the equipment is realized.

The RCM analysis adopts a functional approach and its main objective is to reduce the maintenance cost by focusing on the most important functions of the system and avoiding or removing maintenance actions that are not strictly necessary. The relevant economic decisions are made in terms of known and projected life-cycle maintenance and logistic support costs. Maintenance aspects should preferably be considered during system design from the early conceptual phase and the detailed maintenance strategies should also be established before the system is put into operation.

With RCM, more efficient life-time maintenance and logistics support programs can be developed using a decision logic analysis process that focuses on the consequences of failure. Use of RCM decision logic facilitates the development of high quality maintenance plans in less time and at lower costs. The logic process is applied to each critical item and judgments are made to achieve optimum maintenance task and schedule.

RCM techniques are applied during system design and development processes and reapplied after deployment during operation as a part of sustaining engineering activity. The RCM derived maintenance plans greatly extend useful life of a hardware system, prevent a decrease of reliability and/or deterioration of safety, and reduce maintenance costs as well as total life cycle cost. Also, a well planned RCM program leads to the establishment of better diagnostic and failure indicators which aids in detecting failures and suitable maintenance tasks and determination and verification of the condition of the hardware. The various tasks considered in the RCM approach are all related to failures and functional degradation. The flow of information into and within in RCM program is a continuing process where analysis performed during its development are based on reliability design data and that during field service are based on operational experience data. RCM strategy employs preventive, predictive and proactive maintenance technologies in an integrated manner to increase confidence that a machine will operate dependably over an extended life cycle. The integrated approach of various techniques is required, as no single technique is sufficient to accurately understand the problems of complex equipment. However, in combination, the various technologies provide a powerful set of capabilities of deriving a holistic picture of machine health. The ability to use the various techniques focused around reliability affords an opportunity to move beyond fault detection towards developing a meaningful and valuable tool for a maintenance improvement program

3.2 CONCEPT OF RELIABILITY

The concept of reliability has been known for a number of years, but it has assumed greater significance and importance during the past decade, particularly due to impact of automation, development in complex missile and space programs. Reliability of a system or device is the probability that will give satisfactory performance for a specified period of time under specified conditions.

The manufacture of highly complex equipment has served to focus greater attention on reliability. The complex products, equipments are made up of hundreds or thousands of components whose individual reliability determines the reliability of the entire equipment. Using various types of materials and fabricating operations, the industry has to build reliable performance into equipment and the products manufactured.

Why do chronic losses arise, and not decrease? The reason, in brief is low equipment reliability. Reliability here means the probability that facilities, equipment, and system will function as required during a specified period under given condition. It can also be termed the probability that no problems will occur during a given period. This low reliability leads to the occurrence of failures or defects, because their occurrence cycle is short, the losses become chronic.

Reliability consists of inherent reliability and use reliability. The former stems from design, becoming fixed at the stages of design and manufacturing. The later results from the way the equipment is used, arising poor conditions or methods of use. Inherent and use reliability can be subdivided as follows, and the overall reliability will be their cumulative product.

3.2.1 INHERENT RELIABILITY

(a) Design Reliability:

Stemming from design this reliability is affected by the following factors:

- Jigs / tools unmatched to parts shapes.
- Problems in the mechanism itself.
- Problems in the selection of parts.
- Problems in the detection system.
- Short parts life.

(b) Manufacturing Reliability:

This reliability derives from poor manufacturing or assembly of parts, i.e. problems occur because of incomplete manufacturing/assembly of parts. They are due to the following factors:

- Problems in accuracy of parts size.
- Problems of parts shapes.
- Problems in assembly arrangements.

(c) Installation Reliability:

This reliability is affected by poor installation arrangements, problems occur because of incomplete or improper installation due to the following factors:

- Occurrence of vibration due to poor installation arrangements.
- Insufficient levelness.
- Incomplete tubing/wiring due to poor installation arrangements.

3.2.2 USE RELIABILITY

(a) **Operation Reliability:**

This reliability is affected by poor operational behavior. They are due to the following factors:

- Operation errors.
- Setup and adjustment errors.
- Lack of thorough preparation of basic conditions.
- Use condition errors.

(b) **Maintenance Reliability:**

This reliability is affected by poor maintenance, quality problems occur because of incomplete maintenance due to such factors as:

- Parts replacement errors.
- Poor assembly accuracy.

Generally, problems resulting from poor use reliability are many, while those from poor design reliability are few. When failures or defects occur, it is necessary to examine to which type of reliability decline they are related. Low reliability is considered to arise because research on the manner of using equipment is insufficient. This research is essentially the study of the expertise in using the equipment, consisting of technology for using the equipments skillfully and to optimum effect.

To develop the technology for optimal use of equipment, research is required on the conditions to be possessed by equipment to attain better quality, to raise the utilization ratio (time, speed), and to enhance the maintainability and research on the basic arrangements regarding the equipment proper and peripheral devices to obtain the best performance from the equipment. Technology for skilful uses of equipment necessitates research on the role of operators in operation, adjustment and detection and handling of abnormalities to keep the equipment in an optimum state.

Even if the technology for optimum use of equipment is fairly advanced, problems occur if the capability of the operators who use the equipment is insufficient, and if they do not perform their work, as they should. Conversely, even if the operation skills of operators are excellent and they perform their work properly, trouble may be unavoidable if the equipment itself has problems. In either case effectiveness will be halved. Therefore, it is necessary for both operator capability and equipment condition to be on the same level, just like two opposing wheels on a vehicle. Only then will overall efficiency improvement of a man-machine system become possible.

3.3 CONCEPT OF RCM

RCM is technique for developing a maintenance program and is designed to balance the cost and benefits. To achieve this, the desired system performance standards are of each failure is identified and likelihood of failure is recognized. Maintenance tasks are chosen to address each failure by using a set of applicability and effectiveness criterion. The following definitions will help in understanding the concept of RCM:

- RCM is a process used to determine the maintenance requirements of any physical asset, in its operating context.
- RCM is a process used to determine what must be done to ensure that any physical asset continues to fulfil its intended functions in its present operating context.
- RCM is method for developing and selecting maintenance design alternatives based on safety, operational and economic criteria. It employs a system perspective in its analysis of system functions, failure of functions and prevention of these failures.
- RCM is a system consideration of system functions, the way function can fail and a priority based consideration of safety and economics that identifies applicable and effective PM tasks.

3.4 EVOLUTION OF RCM CONCEPT

Since the 1930s the evolution of maintenance can be traced through three generations.

First generation: It covers the period up to World War II. Industry was not highly mechanised, equipments were simple and over designed. Hence, the maintenance was easy. The need for skills was also lower.

Second generation: By 1950s due to increased mechanisation complex machines were evolved. Hence, concept of preventive maintenance (PM) was introduced. In 1960s, this consisted of mainly equipment overhauls at regular intervals. Maintenance planning and control systems were developed to control the maintenance costs.

Third generation: Since the mid-1970s, the changes in industry have gathered momentum. The changes can be classified under the heading of new expectations, new research and new techniques.

New expectations**:** With the advent of mechanisation and automation, availability and reliability have assumed significant status. Similarly other requirements like quality standards, safety, environment protection, longer equipment life are to be met with effective control over maintenance costs. The following table shows how expectations of maintenance have evolved.

Table – 3.1 Growing Expectation of Maintenance:

First generation (1940s, 1950s)	Second generation (1960s, 1970s.)	Third generation (1980s, 1990s, 2000)
Fix it when it broke	Higher plant availability Longer equipment life Lower costs	Higher plant availability and reliability Greater safety Better product quality No damage to the environment Longer equipment life Greater effectiveness.

New research: New research has shown that there is less and less connection between operating age of most of the assets and how likely they are to fail. Second generation has introduced the concept of bathtub curve. Third generation research has however revealed that six failure patterns actually occur in practice.

New techniques: Many new developments in a number of different fields from the classical emphasis on overhauls and administrative system have occurred as shown in table 3.2. The new developments include decision support tools, new maintenance techniques, a major shift in organisational thinking. A major challenge before maintenance people is to select suitable techniques for a particular organisation from the point of view of improving assets performance at reduced cost.

Table – 3.2 The Changing Maintenance Techniques:

First generation (1940s, 1950s)	Second generation (1960s, 1970s)	Third generation (1980s, 1990s, 2000s)
Fix it when it broke	System for planning and controlling work Big slow computers	Condition monitoring. Design for reliability and maintainability Hazards studies Small fast computers Failure mode and effect analysis Multiskiling and teamwork.

Comparison of three models of maintenance is illustrated in table 3.3. The first generation model was relevant when the industry was not highly mechanised and so downtime was not an important parameter to be concentrated upon. Equipment was very simple and over designed, so it was reliable and easy to repair. There was no need for systematic maintenance.

Table – 3.3 Comparison of Maintenance Models:

First generation	Second generation	Third generation
Corrective maintenance	PM based on bathtub theory	Condition monitoring Total productive maintenance Reliability centred maintenance

Subsequently, due to introduction of just-in-time system, downtime came in sharper focus. Due to automation and mechanization reliability and availability became key issues. Safety and environmental expectations are essentially to be fulfilled. Whereas the cost of maintenance is rising in absolute terms and proportion of total expenditure due to global competition the industries started searching avenues for cost reduction. Conventional PM methodology does not fulfil these requirements. The third generation models attempt to focus its attention on these aspects. Condition monitoring tries to measure the equipment health by measuring some parameter over a period of time. RCM start with a comprehensive zero based review of requirement of each asset in its operating context and it has become rapidly the cornerstone of third generation.

3.5 RCM METHODOLOGY

The salient features of RCM methodology are presented in the flow diagram as shown in Fig. 3.1

System Selection and Information Collection

↓

System Boundary Definition

↓

System Description and Functional Block Diagram

↓

System Functions and Functional Failures

↓

Failure mode and Effect Analysis

↓

Logic Tree Analysis

↓

Tasks Selection

Fig. 3.1: Flow Diagram of RCM Methodology

3.5.1 SYSTEM SELECTION AND INFORMATION COLLECTION

Various factors such as large PM actions or costs, large corrective maintenance actions or cost, safety and environmental issues are considered for selection of system. The documents such as system, schematics and/or block diagrams, equipment history files, vendor manuals, system operation manuals are need to be referred for collection of information. The system is selected as a starting point for RCM process since it has got more failure modes for comparison for meaningful priority rankings of limited PM resources. The level on assembly can be identified as part (e.g. gears), components (e.g. valves, pumps), system (e.g. steam supply, air supply), and plant.

3.5.2. SYSTEM BOUNDARY DEFINITION

Major equipment included in the system is identified with primary physical boundaries. Precise boundary definition is important for two significant aspects. Firstly to make sure that the potentially important functions are not neglected and secondly, boundary will be determining factor in establishing what comes into the system by way of power signals, flow heat, etc. (IN interfaces) and what leaves the system (OUT interfaces). This helps in constructing functional block diagram.

3.5.3. SYSTEM DESCRIPTION AND FUNCTIONAL BLOCK DIAGRAM

The various types of information developed in this phase are as following:

1. System description revealing the functional description, redundancy features, protection features etc.
2. Functional block diagram indicating top-level representation of major system functions.
3. IN/OUT interfaces
4. System work breakdown structure (SWBS) to describe the compilation of the equipment lists for each of functional subsystems on functional block diagram.
5. Equipment history of failures during past 2 or 3 years.

3.5.4 SYSTEM FUNCTIONS AND FUNCTIONAL FAILURES

Information in the previous steps provides the basis for defining system functions. This is necessary to satisfy the first principle of RCM to preserve system functions.

The development of OUT interfaces constitutes the primary source of information for system functions. Function statements are developed for each functional subsystem by capturing every output interface. In functional failure statements, focus is on loss of functions not on equipment.

3.5.5 FAILURE MODE AND EFFECT ANALYSIS

Failure Mode And Effect Analysis (FMEA) is a technique used to quantify and rank critical failures in product or process design. It involves identifying all functional and cosmetic characteristics. Then, for each characteristic, FMEA identifies a list of potential failures and their impact on overall product performance. Also, the likelihood as well as the severity of the failure is estimated.

In this, the specific component failure modes (how the component must fail in order to produce functional failure) and the root cause for each failure mode are defined, initially. Finally, the consequence of the failure mode is done at three levels of consideration, locally at the level of component, at the system level and plant level. The two primary reasons for conducting effect analysis are:

- To assure that the failure mode in question does in fact have a potential relationship to the functional failure being studied.
- To introduce initial screening of failure modes those are not detrimental.

3.5.6 LOGIC TREE ANALYSIS

Purpose of this step is to prioritize the emphasis and resources that should be devoted to each failure. It recognizes the fact that all functions, functional failure and failure modes are not treated equal. The Logic Tree is developed from the top, unwanted event, in branches showing the different event paths. Component failure events represented in the tree are progressively redefined in terms of lower resolution event until the basic events on which a good quality failure data are available and encountered. The events are combined logically by use of gate symbols, which shows the structure of Logic Tree. Using the Logic Tree Analysis, the probability of the top event or the top event frequency can be calculated by providing the information on the basic event probabilities.

3.5.7 TASKS SELECTION

PM Task selection in RCM process requires that each task meet the applicable and effective test, which is defined as follows:

Applicable*:* The task will prevent or mitigate failure, detect onset of a failure or discover a hidden failure.

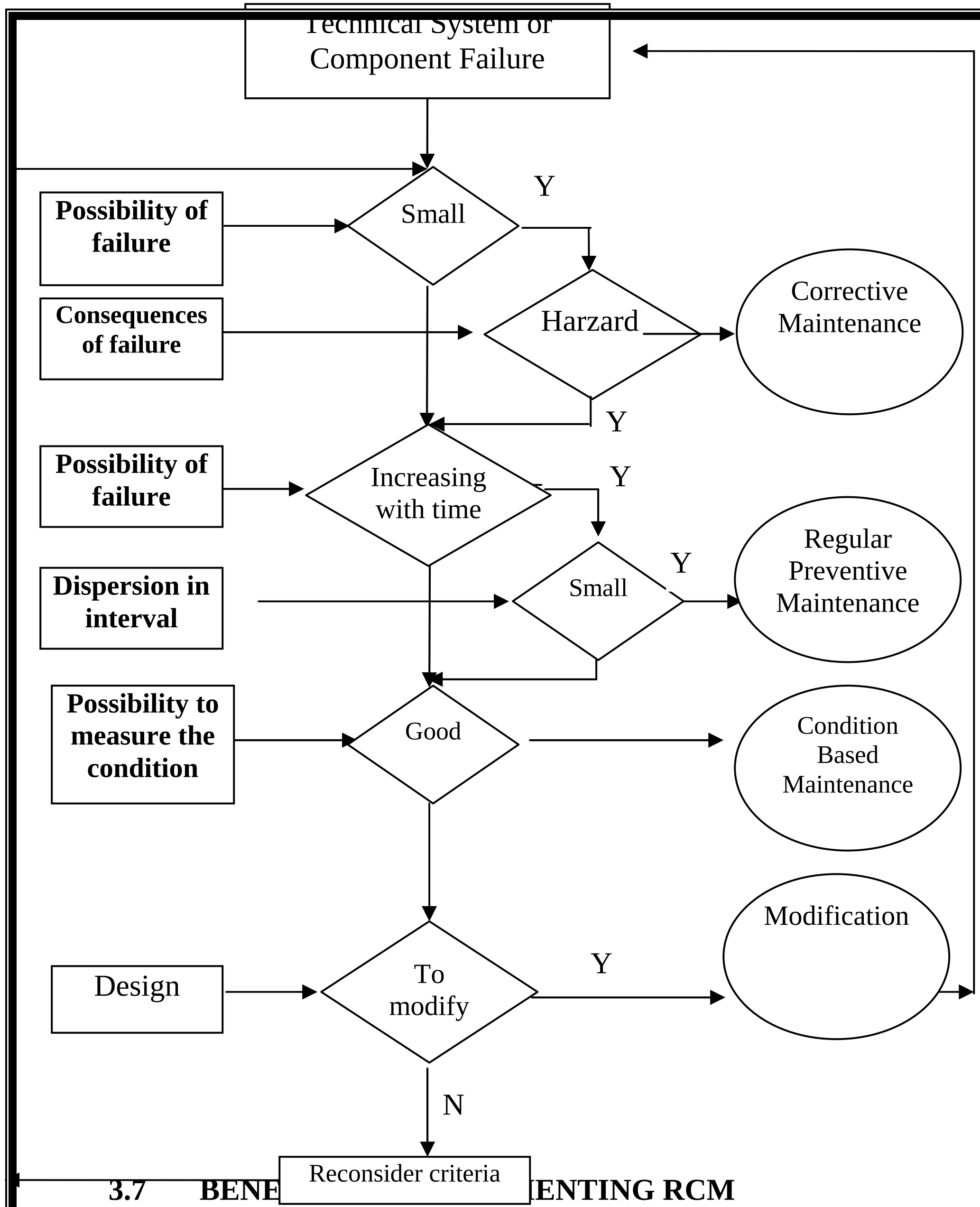
Effective*:* The task is most cost-effective option.

RCM, tasks are designed to prevent three types of failure:

- Dangerous failures injurious to the public, employees or to the environment, such as boiler safety valve, or the rupture of a tank of volatile chemicals.
- Expensive failures where the consequences are operational downtime and large breakdown such as failure of the chain in an auto assembly line.
- Frequently failures that happen continually and are disruptive to the work environment resulting in high repair cost.

3.6 RCM DECISION LOGIC

RCM decision logic is used to guide the analyst through a question and answer process. The input to RCM decision logic is the dominant failure modes from the failure mode and effect analysis. The decision of RCM decision logic is to arrive at the most suitable and effective maintenance task application to the maintenance significant items (MSI). RCM decision logic is shown in Fig. 3.2



3.7 BENE… …ENTING RCM

Fig. 3.2 : RCM Decision Logic

RCM fo … omplex redundant systems have reliability directly engineered into their design. The reliability of a system is reduced if maintenance tasks and frequencies are not its integral component. Over maintenance reduces the system reliability on account of maintenance induced failures. For highly reliable system, reliability very often is reduced due to human intervention under the pretext of PM. Therefore RCM methodology has been successful in building up highly reliable systems. RCM methodology helps in achieving the following:

- High quality, cost effective maintenance plans in less time.
- Assurance that all maintenance important parts and their failure mode are critically considered in the development of maintenance programs.
- Increased probability that the level and content of the maintenance requirement is optimally specified.
- Provides the basis for routine, on-line information sharing among engineering operations and maintenance staff.
- Longer useful life of expensive assets.
- Improved safety of equipment and plant personnel.
- Better environment protection.
- Improved operating performance in terms of output, quality and customer service.

.8 MISCONCEPTIONS ABOUT RCM

1. ***RCM will eliminate breakdown:*** RCM can only help in reducing the number of breakdowns and their severity and consequences.

2. ***RCM is a way of replacing/ attending a part before it breaks:*** RCM is much bigger than that. It is an integrated approach to budgeting, failure analysis, eliminating excessive resource use and permanent correction of problem area.

3. ***All the RCM systems are same and can be copied:*** RCM systems are tailor made, designed to keeping in view the type of equipment, age of equipment product manufactured, type of service, severity of usage, skills of the operator etc.

4. ***RCM increases the workload and expenses*****:** RCM increases uptime, reduces energy usage, reduces unplanned events etc. Only in the beginning a good planning is required.

5 ***Unskilled worker can perform RCM:*** With good procedure and training, unskilled workers can do many routine tasks. For greater return on investment, skilled people must be in loop.

3.9 PITFALLS IN IMPLEMENTING RCM

Most of the organizations try a small project in one place or another, but they have no real organized or structured approach to RCM. The common problems leading to the lack of success with RCM can be summarized as follows:

- **Insufficient Equipment Failure Data:** Historical date about equipment failure is required for the RCM program to be effective. Without the data about the failure, frequency of failure and root cause of the failures, the RCM programs are based on guesswork. RCM is an advanced technique that is used only when effective preventive and predictive programs are in place.
- **Poor Training In The RCM Methodology:** RCM has a structured and logical approach. It doesn't allow an individual to do things in unplanned way. RCM consists of many methodologies some have flexibility, whereas others are more rigid. Some require lot of data others, less. Some approaches are more successful in one industry than other. Thus after selection of the appropriate approach, all the employees involved in RCM efforts should be trained to a high degree of proficiency in the appropriate RCM techniques. Without the training, the RCM efforts will never achieve maximum benefits for the organization.
- **Poor Results in Preventive Maintenance and Periodic Maintenance:** The PM programs have the goal of reducing the reactive maintenance activities to less than 20 percent of all the maintenance work. The PDM programs have the goal of eliminating all unplanned breakdowns. If these two programs are not producing results, the company should not attempt to RCM.
- **Lack of Understanding at Top Management Level:** The lack of understanding about the benefits that can be achieved from a successful RCM program results in poor support from top management. While presenting the concept of RCM to upper management, present the case in terms of cost benefit analysis or return on investment, instead of Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR). Also present the opportunities by highlighting the current losses, amount of losses that can be reduced and cost of RCM program etc.

- **Insufficient Staff for the Program:** RCM task is in addition to maintenance activities and thus required additional funding for tools and personnel. Company should provide the required staff for the success of and getting full benefits of RCM program.
- **Short Term RCM Efforts:** RCM is a valuable tool, especially when coupled with a disciplined maintenance improvement program. It has the capacity to take the organization from reactive to word class maintenance. The journey takes 5 –10 years with no successful short cuts.
- **Lack of Focus:** The organization need to be focused on its vision, the improvement plan and the implementation methodology needed to achieve the goals.

CHAPTER 3: RELIABILITY CENTERED MAINTENANCE METHODOLOGY

3.1 INTRODUCTION

In modern environments with Just In Time (JIT) philosophies and reduced buffer stocks, maintenance is expected to deliver increased performance in terms of efficiency, reliability and plant availability while simultaneously minimizing its impact on production and keeping costs as low as practicable. During the last five decades technical innovations have brought the dream products into reality as well as the production volume has been considerably increased. In the initial phase of this development, product development and manufacturing engineering have been the dominant and significant technical disciplines, whereas Operation and Maintenance (O&M) was given secondary treatment. With the adoption of modern sophisticated machinery, methodologies, expenses/costs incurred on product development and manufacturing engineering are almost at par for similar type of industry with same scale. Therefore O&M offers an opportunity for cost reduction. It also plays a significant role in various issues such as safety and environmental factors.

In most of the cases, the traditional view of maintenance is based on belief that all failures are bad and must be prevented. However, this is practically unrealistic from two angles. Firstly, from purely technical point of view, it is often not feasible to prevent failure. Secondly, even if one could prevent or anticipate all failures it would be cost prohibitive. Hence, it is necessary to have a framework, which can reduce the routine maintenance tasks to sustainable minimum without affecting the plant performance, product quality, safety or environmental integrity. Reliability Centered Maintenance (RCM) provides a network, which enables the users to respond the challenges quickly and simply.

The Concept of Reliability Centered Maintenance (RCM) originated within aircraft industry and later adapted and applied by nuclear power industry, offshore oil and gas industry and military branches. RCM is a method for maintenance planning and can be defined as a systematic consideration of the function of a system, the way a function can fail and priority based consideration of safety and economic aspects that can be used to establish an effective maintenance tasks and schedules. The main focus of RCM is therefore on the system functions and not on system hardware. It is based on the principle that the inherent reliability of equipment is a function of their design and builds quality, and hence an effective maintenance will ensure that the inherent design reliability of the equipment is realized.

The RCM analysis adopts a functional approach and its main objective is to reduce the maintenance cost by focusing on the most important functions of the system and avoiding or removing maintenance actions that are not strictly necessary. The relevant economic decisions are made in terms of known and projected life-cycle maintenance and logistic support costs. Maintenance aspects should preferably be considered during system design from the early conceptual phase and the detailed maintenance strategies should also be established before the system is put into operation.

With RCM, more efficient life-time maintenance and logistics support programs can be developed using a decision logic analysis process that focuses on the consequences of failure. Use of RCM decision logic facilitates the development of high quality maintenance plans in less time and at lower costs. The logic process is applied to each critical item and judgments are made to achieve optimum maintenance task and schedule.

RCM techniques are applied during system design and development processes and reapplied after deployment during operation as a part of sustaining engineering activity. The RCM derived maintenance plans greatly extend useful life of a hardware system, prevent a decrease of reliability and/or deterioration of safety, and reduce maintenance costs as well as total life cycle cost. Also, a well planned RCM program leads to the establishment of better diagnostic and failure indicators which aids in detecting failures and suitable maintenance tasks and determination and verification of the condition of the hardware. The various tasks considered in the RCM approach are all related to failures and functional degradation. The flow of information into and within in RCM program is a continuing process where analysis performed during its development are based on reliability design data and that during field service are based on operational experience data. RCM strategy employs preventive, predictive and proactive maintenance technologies in an integrated manner to increase confidence that a machine will operate dependably over an extended life cycle. The integrated approach of various techniques is required, as no single technique is sufficient to accurately understand the problems of complex equipment. However, in combination, the various technologies provide a powerful set of capabilities of deriving a holistic picture of machine health. The ability to use the various techniques focused around reliability affords an opportunity to move beyond fault detection towards developing a meaningful and valuable tool for a maintenance improvement program

3.2 CONCEPT OF RELIABILITY

The concept of reliability has been known for a number of years, but it has assumed greater significance and importance during the past decade, particularly due to impact of automation, development in complex missile and space programs. Reliability of a system or device is the probability that will give satisfactory performance for a specified period of time under specified conditions.

The manufacture of highly complex equipment has served to focus greater attention on reliability. The complex products, equipments are made up of hundreds or thousands of components whose individual reliability determines the reliability of the entire equipment. Using various types of materials and fabricating operations, the industry has to build reliable performance into equipment and the products manufactured.

Why do chronic losses arise, and not decrease? The reason, in brief is low equipment reliability. Reliability here means the probability that facilities, equipment, and system will function as required during a specified period under given condition. It can also be termed the probability that no problems will occur during a given period. This low reliability leads to the occurrence of failures or defects, because their occurrence cycle is short, the losses become chronic.

Reliability consists of inherent reliability and use reliability. The former stems from design, becoming fixed at the stages of design and manufacturing. The later results from the way the equipment is used, arising poor conditions or methods of use. Inherent and use reliability can be subdivided as follows, and the overall reliability will be their cumulative product.

3.2.1 INHERENT RELIABILITY

(a) Design Reliability:

Stemming from design this reliability is affected by the following factors:

- Jigs / tools unmatched to parts shapes.
- Problems in the mechanism itself.
- Problems in the selection of parts.
- Problems in the detection system.
- Short parts life.

(b) Manufacturing Reliability:

This reliability derives from poor manufacturing or assembly of parts, i.e. problems occur because of incomplete manufacturing/assembly of parts. They are due to the following factors:

- Problems in accuracy of parts size.
- Problems of parts shapes.
- Problems in assembly arrangements.

(c) Installation Reliability:

This reliability is affected by poor installation arrangements, problems occur because of incomplete or improper installation due to the following factors:

- Occurrence of vibration due to poor installation arrangements.
- Insufficient levelness.
- Incomplete tubing/wiring due to poor installation arrangements.

3.2.2 USE RELIABILITY

(a) **Operation Reliability:**

This reliability is affected by poor operational behavior. They are due to the following factors:

- Operation errors.
- Setup and adjustment errors.
- Lack of thorough preparation of basic conditions.
- Use condition errors.

(b) **Maintenance Reliability:**

This reliability is affected by poor maintenance, quality problems occur because of incomplete maintenance due to such factors as:

- Parts replacement errors.
- Poor assembly accuracy.

Generally, problems resulting from poor use reliability are many, while those from poor design reliability are few. When failures or defects occur, it is necessary to examine to which type of reliability decline they are related. Low reliability is considered to arise because research on the manner of using equipment is insufficient. This research is essentially the study of the expertise in using the equipment, consisting of technology for using the equipments skillfully and to optimum effect.

To develop the technology for optimal use of equipment, research is required on the conditions to be possessed by equipment to attain better quality, to raise the utilization ratio (time, speed), and to enhance the maintainability and research on the basic arrangements regarding the equipment proper and peripheral devices to obtain the best performance from the equipment. Technology for skilful uses of equipment necessitates research on the role of operators in operation, adjustment and detection and handling of abnormalities to keep the equipment in an optimum state.

Even if the technology for optimum use of equipment is fairly advanced, problems occur if the capability of the operators who use the equipment is insufficient, and if they do not perform their work, as they should. Conversely, even if the operation skills of operators are excellent and they perform their work properly, trouble may be unavoidable if the equipment itself has problems. In either case effectiveness will be halved. Therefore, it is necessary for both operator capability and equipment condition to be on the same level, just like two opposing wheels on a vehicle. Only then will overall efficiency improvement of a man-machine system become possible.

3.4 CONCEPT OF RCM

RCM is technique for developing a maintenance program and is designed to balance the cost and benefits. To achieve this, the desired system performance standards are of each failure is identified and likelihood of failure is recognized. Maintenance tasks are chosen to address each failure by using a set of applicability and effectiveness criterion. The following definitions will help in understanding the concept of RCM:

- RCM is a process used to determine the maintenance requirements of any physical asset, in its operating context.
- RCM is a process used to determine what must be done to ensure that any physical asset continues to fulfil its intended functions in its present operating context.
- RCM is method for developing and selecting maintenance design alternatives based on safety, operational and economic criteria. It employs a system perspective in its analysis of system functions, failure of functions and prevention of these failures.
- RCM is a system consideration of system functions, the way function can fail and a priority based consideration of safety and economics that identifies applicable and effective PM tasks.

3.4 EVOLUTION OF RCM CONCEPT

Since the 1930s the evolution of maintenance can be traced through three generations.

First generation: It covers the period up to World War II. Industry was not highly mechanised, equipments were simple and over designed. Hence, the maintenance was easy. The need for skills was also lower.

Second generation: By 1950s due to increased mechanisation complex machines were evolved. Hence, concept of preventive maintenance (PM) was introduced. In 1960s, this consisted of mainly equipment overhauls at regular intervals. Maintenance planning and control systems were developed to control the maintenance costs.

Third generation: Since the mid-1970s, the changes in industry have gathered momentum. The changes can be classified under the heading of new expectations, new research and new techniques.

***New expectations*:** With the advent of mechanisation and automation, availability and reliability have assumed significant status. Similarly other requirements like quality standards, safety, environment protection, longer equipment life are to be met with effective control over maintenance costs. The following table shows how expectations of maintenance have evolved.

Table – 3.1 Growing Expectation of Maintenance:

First generation (1940s, 1950s)	Second generation (1960s, 1970s.)	Third generation (1980s, 1990s, 2000)
Fix it when it broke	Higher plant availability Longer equipment life Lower costs	Higher plant availability and reliability Greater safety Better product quality No damage to the environment Longer equipment life Greater effectiveness.

New research: New research has shown that there is less and less connection between operating age of most of the assets and how likely they are to fail. Second generation has introduced the concept of bathtub curve. Third generation research has however revealed that six failure patterns actually occur in practice.

New techniques: Many new developments in a number of different fields from the classical emphasis on overhauls and administrative system have occurred as shown in table 3.2. The new developments include decision support tools, new maintenance techniques, a major shift in organisational thinking. A major challenge before maintenance people is to select suitable techniques for a particular organisation from the point of view of improving assets performance at reduced cost.

Table – 3.2 The Changing Maintenance Techniques:

First generation (1940s, 1950s)	Second generation (1960s, 1970s)	Third generation (1980s, 1990s, 2000s)
Fix it when it broke	System for planning and controlling work Big slow computers	Condition monitoring. Design for reliability and maintainability Hazards studies Small fast computers Failure mode and effect analysis Multiskiling and teamwork.

Comparison of three models of maintenance is illustrated in table 3.3. The first generation model was relevant when the industry was not highly mechanised and so downtime was not an important parameter to be concentrated upon. Equipment was very simple and over designed, so it was reliable and easy to repair. There was no need for systematic maintenance.

Table – 3.3 Comparison of Maintenance Models:

First generation	Second generation	Third generation
Corrective maintenance	PM based on bathtub theory	Condition monitoring Total productive maintenance Reliability centred maintenance

Subsequently, due to introduction of just-in-time system, downtime came in sharper focus. Due to automation and mechanization reliability and availability became key issues. Safety and environmental expectations are essentially to be fulfilled. Whereas the cost of maintenance is rising in absolute terms and proportion of total expenditure due to global competition the industries started searching avenues for cost reduction. Conventional PM methodology does not fulfil these requirements. The third generation models attempt to focus its attention on these aspects. Condition monitoring tries to measure the equipment health by measuring some parameter over a period of time. RCM start with a comprehensive zero based review of requirement of each asset in its operating context and it has become rapidly the cornerstone of third generation.

3.5 RCM METHODOLOGY

The salient features of RCM methodology are presented in the flow diagram as shown in Fig. 3.1

System Selection and Information Collection

↓

System Boundary Definition

↓

System Description and Functional Block Diagram

↓

System Functions and Functional Failures

↓

Failure mode and Effect Analysis

↓

Logic Tree Analysis

↓

Tasks Selection

Fig. 3.1: Flow Diagram of RCM Methodology

3.5.1 SYSTEM SELECTION AND INFORMATION COLLECTION

Various factors such as large PM actions or costs, large corrective maintenance actions or cost, safety and environmental issues are considered for selection of system. The documents such as system, schematics and/or block diagrams, equipment history files, vendor manuals, system operation manuals are need to be referred for collection of information. The system is selected as a starting point for RCM process since it has got more failure modes for comparison for meaningful priority rankings of limited PM resources. The level on assembly can be identified as part (e.g. gears), components (e.g. valves, pumps), system (e.g. steam supply, air supply), and plant.

3.5.2. SYSTEM BOUNDARY DEFINITION

Major equipment included in the system is identified with primary physical boundaries. Precise boundary definition is important for two significant aspects. Firstly to make sure that the potentially important functions are not neglected and secondly, boundary will be determining factor in establishing what comes into the system by way of power signals, flow heat, etc. (IN interfaces) and what leaves the system (OUT interfaces). This helps in constructing functional block diagram.

3.5.3. SYSTEM DESCRIPTION AND FUNCTIONAL BLOCK DIAGRAM

The various types of information developed in this phase are as following:

6. System description revealing the functional description, redundancy features, protection features etc.
7. Functional block diagram indicating top-level representation of major system functions.
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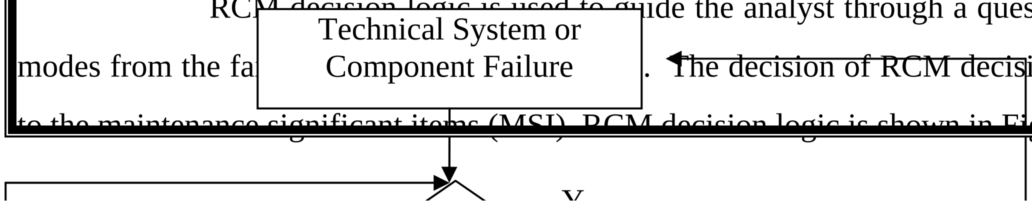

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The RCM analysis adopts a functional approach and its main objective is to reduce the maintenance cost by focusing on the most important functions of the system and avoiding or removing maintenance actions that are not strictly necessary. The relevant economic decisions are made in terms of known and projected life-cycle maintenance and logistic support costs. Maintenance aspects should preferably be considered during system design from the early conceptual phase and the detailed maintenance strategies should also be established before the system is put into operation.

With RCM, more efficient life-time maintenance and logistics support programs can be developed using a decision logic analysis process that focuses on the consequences of failure. Use of RCM decision logic facilitates the development of high quality maintenance plans in less time and at lower costs. The logic process is applied to each critical item and judgments are made to achieve optimum maintenance task and schedule.

RCM techniques are applied during system design and development processes and reapplied after deployment during operation as a part of sustaining engineering activity. The RCM derived maintenance plans greatly extend useful life of a hardware system, prevent a decrease of reliability and/or deterioration of safety, and reduce maintenance costs as well as total life cycle cost. Also, a well planned RCM program leads to the establishment of better diagnostic and failure indicators which aids in detecting failures and suitable maintenance tasks and determination and verification of the condition of the hardware. The various tasks considered in the RCM approach are all related to failures and functional degradation. The flow of information into and within in RCM program is a continuing process where analysis performed during its development are based on reliability design data and that during field service are based on operational experience data. RCM strategy employs preventive, predictive and proactive maintenance technologies in an integrated manner to increase confidence that a machine will operate dependably over an extended life cycle. The integrated approach of various techniques is required, as no single technique is sufficient to accurately understand the problems of complex equipment. However, in combination, the various technologies provide a powerful set of capabilities of deriving a holistic picture of machine health. The ability to use the various techniques focused around reliability affords an opportunity to move beyond fault detection towards developing a meaningful and valuable tool for a maintenance improvement program

3.2 CONCEPT OF RELIABILITY

The concept of reliability has been known for a number of years, but it has assumed greater significance and importance during the past decade, particularly due to impact of automation, development in complex missile and space programs. Reliability of a system or device is the probability that will give satisfactory performance for a specified period of time under specified conditions.

The manufacture of highly complex equipment has served to focus greater attention on reliability. The complex products, equipments are made up of hundreds or thousands of components whose individual reliability determines the reliability of the entire equipment. Using various types of materials and fabricating operations, the industry has to build reliable performance into equipment and the products manufactured.

Why do chronic losses arise, and not decrease? The reason, in brief is low equipment reliability. Reliability here means the probability that facilities, equipment, and system will function as required during a specified period under given condition. It can also be termed the probability that no problems will occur during a given period. This low reliability leads to the occurrence of failures or defects, because their occurrence cycle is short, the losses become chronic.

Reliability consists of inherent reliability and use reliability. The former stems from design, becoming fixed at the stages of design and manufacturing. The later results from the way the equipment is used, arising poor conditions or methods of use. Inherent and use reliability can be subdivided as follows, and the overall reliability will be their cumulative product.

3.2.1 INHERENT RELIABILITY

(a) Design Reliability:

Stemming from design this reliability is affected by the following factors:

- Jigs / tools unmatched to parts shapes.
- Problems in the mechanism itself.
- Problems in the selection of parts.
- Problems in the detection system.
- Short parts life.

(b) Manufacturing Reliability:

This reliability derives from poor manufacturing or assembly of parts, i.e. problems occur because of incomplete manufacturing/assembly of parts. They are due to the following factors:

- Problems in accuracy of parts size.
- Problems of parts shapes.
- Problems in assembly arrangements.

(c) Installation Reliability:

This reliability is affected by poor installation arrangements, problems occur because of incomplete or improper installation due to the following factors:

- Occurrence of vibration due to poor installation arrangements.
- Insufficient levelness.
- Incomplete tubing/wiring due to poor installation arrangements.

3.2.2 USE RELIABILITY

(a) **Operation Reliability:**

This reliability is affected by poor operational behavior. They are due to the following factors:

- Operation errors.
- Setup and adjustment errors.
- Lack of thorough preparation of basic conditions.
- Use condition errors.

(b) **Maintenance Reliability:**

This reliability is affected by poor maintenance, quality problems occur because of incomplete maintenance due to such factors as:

- Parts replacement errors.
- Poor assembly accuracy.

Generally, problems resulting from poor use reliability are many, while those from poor design reliability are few. When failures or defects occur, it is necessary to examine to which type of reliability decline they are related. Low reliability is considered to arise because research on the manner of using equipment is insufficient. This research is essentially the study of the expertise in using the equipment, consisting of technology for using the equipments skillfully and to optimum effect.

To develop the technology for optimal use of equipment, research is required on the conditions to be possessed by equipment to attain better quality, to raise the utilization ratio (time, speed), and to enhance the maintainability and research on the basic arrangements regarding the equipment proper and peripheral devices to obtain the best performance from the equipment. Technology for skilful uses of equipment necessitates research on the role of operators in operation, adjustment and detection and handling of abnormalities to keep the equipment in an optimum state.

Even if the technology for optimum use of equipment is fairly advanced, problems occur if the capability of the operators who use the equipment is insufficient, and if they do not perform their work, as they should. Conversely, even if the operation skills of operators are excellent and they perform their work properly, trouble may be unavoidable if the equipment itself has problems. In either case effectiveness will be halved. Therefore, it is necessary for both operator capability and equipment condition to be on the same level, just like two opposing wheels on a vehicle. Only then will overall efficiency improvement of a man, machine system become possible.

3.5 CONCEPT OF RCM

RCM is technique for developing a maintenance program and is designed to balance the cost and benefits. To achieve this, the desired system performance standards are of each failure is identified and likelihood of failure is recognized. Maintenance tasks are chosen to address each failure by using a set of applicability and effectiveness criterion. The following definitions will help in understanding the concept of RCM:

- RCM is a process used to determine the maintenance requirements of any physical asset, in its operating context.
- RCM is a process used to determine what must be done to ensure that any physical asset continues to fulfil its intended functions in its present operating context.
- RCM is method for developing and selecting maintenance design alternatives based on safety, operational and economic criteria. It employs a system perspective in its analysis of system functions, failure of functions and prevention of these failures.
- RCM is a system consideration of system functions, the way function can fail and a priority based consideration of safety and economics that identifies applicable and effective PM tasks.

3.4 EVOLUTION OF RCM CONCEPT

Since the 1930s the evolution of maintenance can be traced through three generations.

First generation: It covers the period up to World War II. Industry was not highly mechanised, equipments were simple and over designed. Hence, the maintenance was easy. The need for skills was also lower.

Second generation: By 1950s due to increased mechanisation complex machines were evolved. Hence, concept of preventive maintenance (PM) was introduced. In 1960s, this consisted of mainly equipment overhauls at regular intervals. Maintenance planning and control systems were developed to control the maintenance costs.

Third generation: Since the mid-1970s, the changes in industry have gathered momentum. The changes can be classified under the heading of new expectations, new research and new techniques.

***New expectations*:** With the advent of mechanisation and automation, availability and reliability have assumed significant status. Similarly other requirements like quality standards, safety, environment protection, longer equipment life are to be met with effective control over maintenance costs. The following table shows how expectations of maintenance have evolved.

Table – 3.1 Growing Expectation of Maintenance:

First generation (1940s, 1950s)	Second generation (1960s, 1970s.)	Third generation (1980s, 1990s, 2000)
Fix it when it broke	Higher plant availability Longer equipment life Lower costs	Higher plant availability and reliability Greater safety Better product quality

		No damage to the environment Longer equipment life Greater effectiveness.

New research: New research has shown that there is less and less connection between operating age of most of the assets and how likely they are to fail. Second generation has introduced the concept of bathtub curve. Third generation research has however revealed that six failure patterns actually occur in practice.

New techniques: Many new developments in a number of different fields from the classical emphasis on overhauls and administrative system have occurred as shown in table 3.2. The new developments include decision support tools, new maintenance techniques, a major shift in organisational thinking. A major challenge before maintenance people is to select suitable techniques for a particular organisation from the point of view of improving assets performance at reduced cost.

Table – 3.2 The Changing Maintenance Techniques:

First generation (1940s, 1950s)	Second generation (1960s, 1970s)	Third generation (1980s, 1990s, 2000s)
Fix it when it broke	System for planning and controlling work Big slow computers	Condition monitoring. Design for reliability and maintainability Hazards studies Small fast computers Failure mode and

		effect analysis
		Multiskiling and teamwork.

Comparison of three models of maintenance is illustrated in table 3.3. The first generation model was relevant when the industry was not highly mechanised and so downtime was not an important parameter to be concentrated upon. Equipment was very simple and over designed, so it was reliable and easy to repair. There was no need for systematic maintenance.

Table – 3.3 Comparison of Maintenance Models:

First generation	Second generation	Third generation
Corrective maintenance	PM based on bathtub theory	Condition monitoring Total productive maintenance Reliability centred maintenance

Subsequently, due to introduction of just-in-time system, downtime came in sharper focus. Due to automation and mechanization reliability and availability became key issues. Safety and environmental expectations are essentially to be fulfilled. Whereas the cost of maintenance is rising in absolute terms and proportion of total expenditure due to global competition the industries started searching avenues for cost reduction. Conventional PM methodology does not fulfil these requirements. The third generation models attempt to focus its attention on these aspects. Condition monitoring tries to measure the equipment health by measuring some parameter over a period of time. RCM start with a comprehensive zero based review of requirement of each asset in its operating context and it has become rapidly the cornerstone of third generation.

3.5 RCM METHODOLOGY

The salient features of RCM methodology are presented in the flow diagram as shown in Fig. 3.1

System Selection and Information Collection

↓

System Boundary Definition

↓

System Description and Functional Block Diagram

↓

System Functions and Functional Failures

↓

Failure mode and Effect Analysis

↓

Logic Tree Analysis

↓

Tasks Selection

Fig. 3.1: Flow Diagram of RCM Methodology

3.5.1 SYSTEM SELECTION AND INFORMATION COLLECTION

Various factors such as large PM actions or costs, large corrective maintenance actions or cost, safety and environmental issues are considered for selection of system. The documents such as system, schematics and/or block diagrams, equipment history files, vendor manuals, system operation manuals are need to be referred for collection of information. The system is selected as a starting point for RCM process since it has got more failure modes for comparison for meaningful priority rankings of limited PM resources. The level on assembly can be identified as part (e.g. gears), components (e.g. valves, pumps), system (e.g. steam supply, air supply), and plant.

3.5.2. SYSTEM BOUNDARY DEFINITION

Major equipment included in the system is identified with primary physical boundaries. Precise boundary definition is important for two significant aspects. Firstly to make sure that the potentially important functions are not neglected and secondly, boundary will be determining factor in establishing what comes into the system by way of power signals, flow heat, etc. (IN interfaces) and what leaves the system (OUT interfaces). This helps in constructing functional block diagram.

3.5.3. SYSTEM DESCRIPTION AND FUNCTIONAL BLOCK DIAGRAM

The various types of information developed in this phase are as following:

11. System description revealing the functional description, redundancy features, protection features etc.
12. Functional block diagram indicating top-level representation of major system functions.
13. IN/OUT interfaces
14. System work breakdown structure (SWBS) to describe the compilation of the equipment lists for each of functional subsystems on functional block diagram.
15. Equipment history of failures during past 2 or 3 years.

3.5.4 SYSTEM FUNCTIONS AND FUNCTIONAL FAILURES

Information in the previous steps provides the basis for defining system functions. This is necessary to satisfy the first principle of RCM to preserve system functions.

The development of OUT interfaces constitutes the primary source of information for system functions. Function statements are developed for each functional subsystem by capturing every output interface. In functional failure statements, focus is on loss of functions not on equipment.

3.5.5 FAILURE MODE AND EFFECT ANALYSIS

Failure Mode And Effect Analysis (FMEA) is a technique used to quantify and rank critical failures in product or process design. It involves identifying all functional and cosmetic characteristics. Then, for each characteristic, FMEA identifies a list of potential failures and their impact on overall product performance. Also, the likelihood as well as the severity of the failure is estimated.

In this, the specific component failure modes (how the component must fail in order to produce functional failure) and the root cause for each failure mode are defined, initially. Finally, the consequence of the failure mode is done at three levels of consideration, locally at the level of component, at the system level and plant level. The two primary reasons for conducting effect analysis are:

- To assure that the failure mode in question does in fact have a potential relationship to the functional failure being studied.
- To introduce initial screening of failure modes those are not detrimental.

3.5.6 LOGIC TREE ANALYSIS

Purpose of this step is to prioritize the emphasis and resources that should be devoted to each failure. It recognizes the fact that all functions, functional failure and failure modes are not treated equal. The Logic Tree is developed from the top, unwanted event, in branches showing the different event paths. Component failure events represented in the tree are progressively redefined in terms of lower resolution event until the basic events on which a good quality failure data are available and encountered. The events are combined logically by use of gate symbols, which shows the structure of Logic Tree. Using the Logic Tree Analysis, the probability of the top event or the top event frequency can be calculated by providing the information on the basic event probabilities.

3.5.7 TASKS SELECTION

PM Task selection in RCM process requires that each task meet the applicable and effective test, which is defined as follows:

Applicable: The task will prevent or mitigate failure, detect onset of a failure or discover a hidden failure.

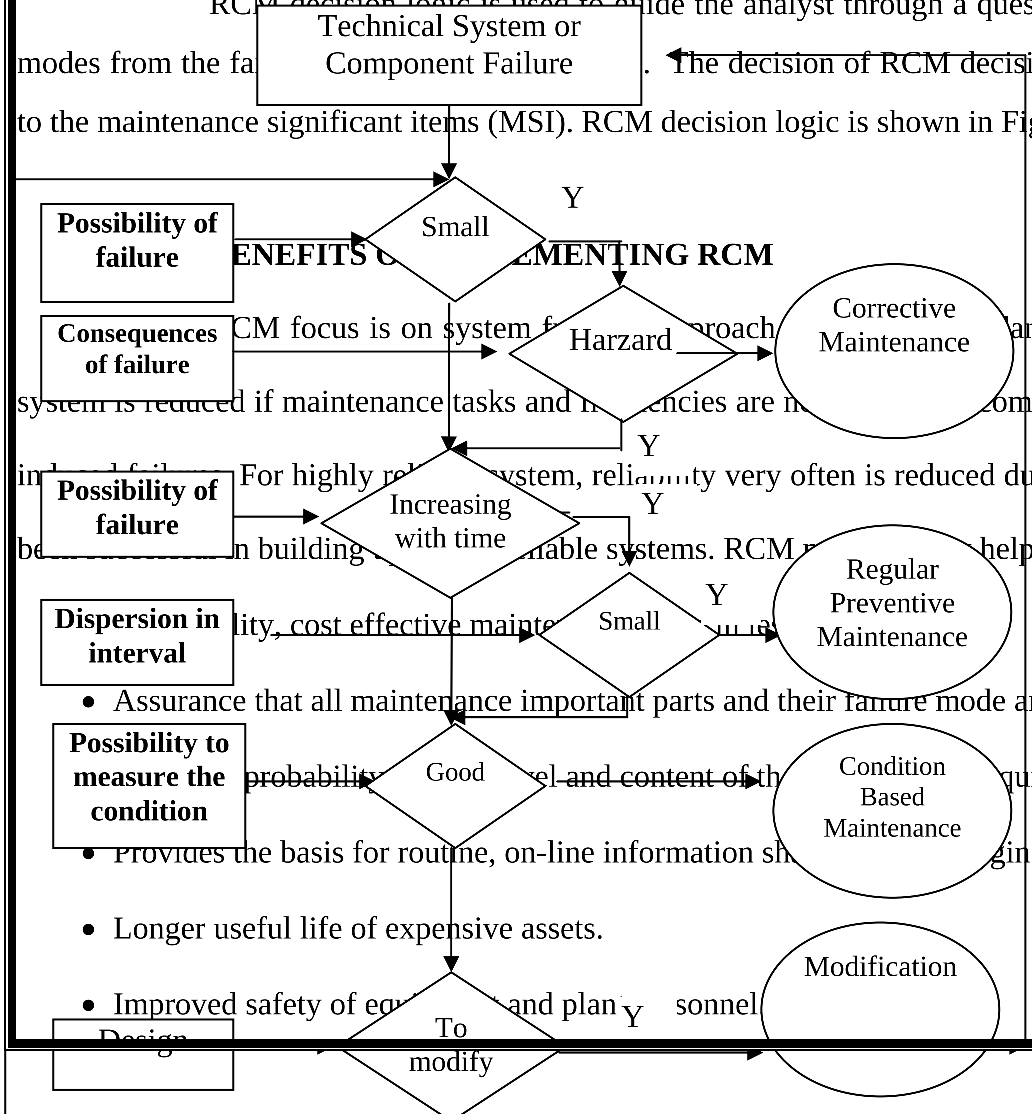
***Effective*:** The task is most cost-effective option

RCM, tasks are designed to prevent three types of failure:

- Dangerous failures injurious to the public, employees or to the environment, such as boiler safety valve, or the rupture of a tank of volatile chemicals.
- Expensive failures where the consequences are operational downtime and large breakdown such as failure of the chain in an auto assembly line.
- Frequently failures that happen continually and are disruptive to the work environment resulting in high repair cost.

3.6 RCM DECISION LOGIC

RCM decision logic is used to guide the analyst through a question and answer process. The input to RCM decision logic is the dominant failure modes from the fa[illegible]. The decision of RCM decision logic is to arrive at the most suitable and effective maintenance task application to the maintenance significant items (MSI). RCM decision logic is shown in Fig. 3.2.



[illegible]ENEFITS O[illegible]EMENTING RCM

[illegible]CM focus is on system f[illegible]roach[illegible]ant systems have reliability directly engineered into their design. The reliability of a system is reduced if maintenance tasks and fr[illegible]encies are n[illegible]omponent. Over maintenance reduces the system reliability on account of maintenance in[illegible] For highly rel[illegible]ystem, reliability very often is reduced due to human intervention under the pretext of PM. Therefore RCM methodology has been successful in building [illegible]nable systems. RCM [illegible] helps in achieving the following:

[illegible]lity, cost effective mainte[illegible]

- Assurance that all maintenance important parts and their failure mode are critically considered in the development of maintenance programs.
- [illegible] probability [illegible]el and content of th[illegible]quirement is optimally specified.
- Provides the basis for routine, on-line information sh[illegible]gineering operations and maintenance staff.
- Longer useful life of expensive assets.
- Improved safety of eq[illegible] and plan[illegible]sonnel

- Better environment protection
- Improved operating performance in terms of output, quality and customer service.

.8 MISCONCEPTIONS ABOUT RCM

1. ***RCM will eliminate breakdown:*** RCM can only help in reducing the number of breakdowns and their severity and consequences.
2. ***RCM is a way of replacing/ attending a part before it breaks:*** RCM is much bigger than that. It is an integrated approach to budgeting, failure analysis, eliminating excessive resource use and permanent correction of problem area.
3. ***All the RCM systems are same and can be copied:*** RCM systems are tailor made, designed to keeping in view the type of equipment, age of equipment product manufactured, type of service, severity of usage, skills of the operator etc.
4. ***RCM increases the workload and expenses*:** RCM increases uptime, reduces energy usage, reduces unplanned events etc. Only in the beginning a good planning is required.
5. ***Unskilled worker can perform RCM:*** With good procedure and training, unskilled workers can do many routine tasks. For greater return on investment, skilled people must be in loop.

3.9 PITFALLS IN IMPLEMENTING RCM

Most of the organizations try a small project in one place or another, but they have no real organized or structured approach to RCM. The common problems leading to the lack of success with RCM can be summarized as follows:

- **Insufficient Equipment Failure Data:** Historical date about equipment failure is required for the RCM program to be effective. Without the data about the failure, frequency of failure and root cause of the failures, the RCM programs are based on guesswork. RCM is an advanced technique that is used only when effective preventive and predictive programs are in place.

- **Poor Training In The RCM Methodology:** RCM has a structured and logical approach. It doesn't allow an individual to do things in unplanned way. RCM consists of many methodologies some have flexibility, whereas others are more rigid. Some require lot of data others, less. Some approaches are more successful in one industry than other. Thus after selection of the appropriate approach, all the employees involved in RCM efforts should be trained to a high degree of proficiency in the appropriate RCM techniques. Without the training, the RCM efforts will never achieve maximum benefits for the organization.
- **Poor Results in Preventive Maintenance and Periodic Maintenance:** The PM programs have the goal of reducing the reactive maintenance activities to less than 20 percent of all the maintenance work. The PDM programs have the goal of eliminating all unplanned breakdowns. If these two programs are not producing results, the company should not attempt to RCM.
- **Lack of Understanding at Top Management Level:** The lack of understanding about the benefits that can be achieved from a successful RCM program results in poor support from top management. While presenting the concept of RCM to upper management, present the case in terms of cost benefit analysis or return on investment, instead of Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR). Also present the opportunities by highlighting the current losses, amount of losses that can be reduced and cost of RCM program etc.
- **Insufficient Staff for the Program:** RCM task is in addition to maintenance activities and thus required additional funding for tools and personnel. Company should provide the required staff for the success of and getting full benefits of RCM program.
- **Short Term RCM Efforts:** RCM is a valuable tool, especially when coupled with a disciplined maintenance improvement program. It has the capacity to take the organization from reactive to word class maintenance. The journey takes 5 –10 years with no successful short cuts.
- **Lack of Focus:** The organization need to be focused on its vision, the improvement plan and the implementation methodology needed to achieve the goals.

CHAPTER: 4 CASE STUDY

4.1 COMPANY PROFILE

UPTRON COLOUR PICTURE TUBES LIMITED, situated at District Ghaziabad, was taken over by the **BPL Group of Companies** in June 1996. The name of the company was changed to "**BPL DISPLAY DEVICES LIMITED,**" in March 1998. After acquiring the company in June 1996, the technical revival was completed in August 1997 and production was commenced in September 1997. Presently 20" and 21" Colour Picture Tubes (CPT) are being manufactured in technical collaboration with Toshiba Corporation, Japan.

The organization is having a very good infrastructure. There is a abundance of engineers, managers, and skilled workers in the company. The company is having a team of 300 technical and commercial staff and Approx 1050 workmen.

In a short span, the company has established a high reputation as quality manufacturer of CPT of internationally acceptable quality. The company has secured ISO 9001: 2000, the Quality Management System and ISO 14001, The Environment Management System. The company received the "Commendation Certificate" for Rajiv Gandhi National Quality Award for the year 2001 and also received first prize in "Excellence in Electronics Components & Materials" for the year 2000-01 from the Ministry of Communications and Information Technology.

The quality improvement measures included Quality Task Force activities followed by TPM activities. TPM activities initiated by Mr. Sueo Yamaguchi of Japan Institute of Plant Maintenance (JIPM) – Japan, included Kaizens, loss structure analysis, defect and scrap reduction projects, model machine activities, 5S activities and regular audits The TPM was also kicked off on 18th April 2002 in the guidance of Mr. Sueo Yamaguchi after studying the better performance of the company. The implementation of TPM system at the plant has resulted the growth in production, improvement in plant yield, improvement in quality, breakdown and wastage reduction etc.

In view of the changing trend in consumer's preferences and their increased inclination for purchasing a flat screen television, the conventional picture tubes market is being rapidly taken over by real flat picture tubes. The Company is manufacturing 21" real flat CPT in the existing line since December 2004 with the technical collaboration LG Phillips, Holland. The real flat picture tubes would enrich the "Product Mix" and improve the salability of tubes leading to higher contribution, as perfectly flat picture tubes market is on its nascent stage and is expanding at a rapid pace in India.

In the coming years, the company in planning to adopt various cost reduction measures including installation of gas turbine for power generation, plant's capacity enhancement from 1.44 million CPT to 1.8 million CPT.

4.2 SYSTEM SELECTION AND INFORMATION COLLECTION

A Numerical Control (NC) machine is selected for RCM analysis. This machine is used to coat the frit glass on the seal edge of the funnel, which has been cleaned in the funnel finish process. The cycle time of machine is Approx. 28.0 second. The view of NC Frit Glass Coating Machine is given in Fig. 4.1.

The system description, operation and maintenance manuals were not easily available hence the interaction was done with production as well as maintenance personnel to collect the maximum possible relevant information. The failure data pertaining the breakdown on the NC Frit Glass Coating Machine for the period of 1st January 2002 to 31st Dec. 2004 were collected from BPL Display Devices Ltd. The machine is selected for RCM analysis keeping in view the following points:

Photo

Fig. 4.1: NC Frit Glass Coating Machine

4.2.1 COST OF MACHINE

The cost of the machine is very high, ranging in lacs. This obviates the fact that the individual spare parts of different assemblies will be very expensive. Therefore, it is very difficult to keep the spare parts of all the vital items needed for immediate replacement in case of failure.

4.2.2 MAINTENANCE COST

The NC machine incorporate complex high technology and sophisticated system, hence the maintenance cost of the machine is very high. As a mechanical asset ages, the maintenance cost generally increases. Maintenance costs increases significantly when the critical wear point in mechanical system is reached.

4.2.3 AVAILABILITY

The NC Machine is highly prolific as compared to other machines, so its longer breakdown / consequences of failure may lead to stop the production. The availability indicates what percentage of time equipment is actually running however, it does not account for defects, reduced speed and other loss factors.

4.2.4 QUALITY

The sealing of panel and funnel is the most critical parameter in the picture tube manufacturing system. Approx 40 % cost of colour television goes to the CPT. The quality of the sealing of the CPT depends on the coating of frit glass on the seal edge of the funnel. The quality parameters should be maintained strictly. Any deviation in the quality control specification may result the heavy rejection like sealing defect, bulb breakage and implosion etc.

4.2.5. SAFETY

NC machine is a compact system and a failure like sparking may lead to multiple failure or even cause personnel injury. A highly inflammable chemical is used to make the frit glass slurry from frit glass powder. The mixing of the chemical and frit glass powder has been done in a fire proof room near the machine keeping in view the safety of the machine and the company.

4.3 SYSTEM BOUNDARY DEFINITION

This machine is very sensitive to the electric supply. The machine goes off in case of fluctuation of electric supply. The m/c runs at constant compressed air pressure, any variation in compressed air pressure leads to functional failure of the m/c. The viscosity of the fit glass slurry is most important parameter, keeping in view the quality of the product and the efficiency of the equipment. During the preparation of fit glass, maintain its viscosity. At least 70% seal as of the funnel should be covered uniformly and weight should be maintained in the process of frit glass coating.

4.4 SYSTEM DESCRIPTION AND FUNCTIONAL BLOCK DIAGRAM

This M/c is used to coat the Frit Glass on the seal edge of 20" and 21" funnels. The seal as of the funnel has been cleaned in the Funnel Finish Process. The Frit Glass is bonding material, which is used to join to parts of CPT i.e. Panel & Funnel. The Toshiba Corporation, Japan manufactured this m/c in 1987.

4.4.1 SPECIFICATIONS

The specifications of the machine are given below:

i) Capacity

Total cycle time ………		**Approx. 28 second**
Funnel transfer time ………		**Approx. 14 second**
Coating time by m/c …….		**Approx. 14 second**
	Maximum	**Approx. 19 second**
	Minimum	**Approx. 9 second**

ii) Dimension (mm) and Weight (kg)

a) Machine Body

1865 (L) x 1200 (W) x 2174 (H), 1200 Kg.

b) NC Control Panel

700 (L) x 600 (W) x 1500 (H), 300 Kg.

iii) Energy and Media

a) Electricity

415 V AC, 50 Hz, 3 Phase, 8 Kw.

b) Compressed Air

5 Kg / Cm^2

4.4.2 STRUCTURE OF NC FRIT GLASS COATING MACHINE

The system block diagram of the NC Frit Glass Coating Machine is shown in Fig. 4.2. The machine consists the following units:

1) Funnel carry and Lifting System: **The operator loads the funnel on the funnel holding device and switch on the machine. The funnel goes forward and lifts the funnel up to desired level. After the frit glass coating funnel comes down and returns to original position, then operator unloads the funnel, do the repair of frit glass coating with tissue paper and loads the funnel on conveyor. The funnel carry and lifting system is shown in Fig. 4.3.**

Photo

Fig. 4.3: Funnel Carry and Lifting System

2) Funnel Stopper System: **When the operator switch on the machine, the funnel stopper come down and gives the position to the funnel. When funnel lifts upward and touches the micro switch of stopper, the stopper goes upward. The funnel stopper system is shown in Fig. 4.4.**

3) Funnel Gauging System: **When funnel goes upward, gauging unit goes forward, hold and do the centering of the funnel. After seal edge coating of funnel, the gauging unit goes backward and the funnel comes down. The funnel gauging system is shown in Fig. 4.4.**

Photo

Fig. 4.4: Funnel Stopper and Gauging System

4) Axes Drive System: **The function of the axes drive system is to provide the motion to the frit glass tank unit in x-axis and y-axis direction during the frit glass coating. The motion from servomotors goes to x-axis and y-axis with the help of bevel gears and ball screws. The axes drive system is shown in the Fig. 4.5.**

Photo

Fig. 4.5: Axes Drive System

5) Frit Glass Tank Unit: **This unit consists the motor, coupling and agitator, to rotate frit glass in the frit tank unit. The unit also consists the shutter for opening & closing of the frit glass tank hole. The frit glass tank unit shown in the Fig. 4.6.**

Photo

Fig. 4.6: Frit Glass Tank Unit

4.4.3 ELECTRICAL AND CONTROL SYSTEM

It feeds the power supply and signals to all the assemblies of the system. Its details are given below:

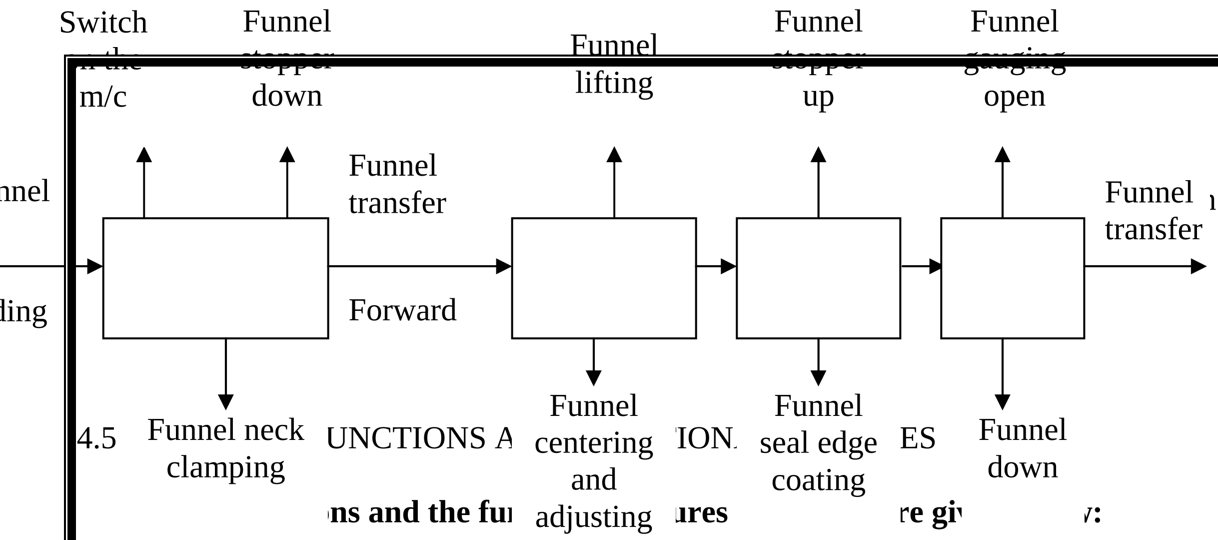
- **NC Controller**
- **Programmable Logical Controller**
- **AC Servo Motor**
- **Electric Motor**
- **Photo Sensor**
- **Micro Switch**
- **Reed Switch**
- **Proximity Switch**
- **Limit Switch**
- **Automatic Voltage Regulator (AVR)**

4.4.4 LUBRICATION SYSTEM

NC Controller controls the Operation of lubrication system as per requirement. Its function is to provide lubrication of all moving parts.

FUNCTIONAL BLOCK DIAGRAM

The functional block diagram is composed solely of functions and no equipment appears in the diagram. The functional block diagram indicating IN and OUT interfaces is shown in Fig.4.7.



4.5 …UNCTIONS A…ION…ES

…ns and the fu… …ures … …re gi… …v:

4.5.1 FUNNEL CARRY AND LIFTING SYSTEM

Fig. 4.7: Functional Block Diagram of NC Frit Coating M/C

This unit is used to carry the funnel, loaded by the operator up to the coating position. The neck chuck is used to position the neck of the funnel loaded on funnel holder at loading / unloading position. The funnel is transferred horizontally to the coating position by air cylinder and then the funnel is lifted by air cylinder. The seal edge height of the funnel is maintained in that state until the frit glass coating finishes.

4.5.2 FUNNEL STOPPER SYSTEM

This unit is used to position the funnel, which has been transferred and lifted, up to coating position. When the machine is started, funnel stopping mechanism is lowered by stopper cylinder, funnel stopping mechanism receives the funnel which has been lifted by lifter cylinder to keep the seal edge height at constants level.

4.5.3 FUNNEL GAUGING SYSTEM

This unit is also used to position the funnel for frit glass coating. When the funnel stopper adjusts the height of the funnel, the gauging system goes forward, hold and adjust the funnel with the help of rollers. After adjusting the funnel, the funnel stopper system goes upward and frit glass coating takes place. Funnel gauging system goes to original after finishing the frit glass coating.

4.5.4 X AND Y AXES UNIT

These units are used to traverse the frit tank unit in x -axis direction and y - axis direction during frit glass coating. The frit tank unit is installed on y-axis unit and traverse in x -axis and y-axis direction by NC controller. The traverse speed shall be usually 120 mm/s, but the speed can be adjust by changing over the select switch in NC controller with in the range ± 50% however the Max. Speed shall be 200 mm/s. The proximity switches send the home position signal and deceleration signal in x-axis and y-axis direction to NC controller through the intermediation of the relay. The end signals and the over travel signals are sent to NC controller without any intermediation.

4.5.5 FRIT GLASS TANK UNIT

This unit is used to store and discharge the frit glass slurry. This unit has the shutter and the agitator. On auto mode, NC controller controls the shutter and agitator switch and variable resistor control the agitator speed. Agitator switch is installed at switching box.

The System functions and functional failures are shown in the table 4.1.

TABLE 4.1 SYSTEM FUNCTIONS AND FUNCTIONAL FAILURES

Sr. No.	Name of Component	Function	Functional Failures
1.	Funnel holding device	To hold the funnel	Neck chuck broken Neck chuck wear out Check nut loose Bearing defective Neck holding ring wear out
2.	Stopper plate	To give the position to	Stripe wear out

		the funnel	Stripe broken Stripe loose
3.	Frit tank unit	To keep the frit glass slurry	Shutter not open Shutter wear out Pin loose
4.	Agitator	To mix the frit glass slurry in the frit tank unit	Shaft bend Shaft wear out Blade bend Blade damage Ring bend Screw loose

5.	Coupling	Join the two parts	Misalignment Wear out
6.	Agitator motor	To drive the agitator	Slip in gears Winding burnt out Capacitor defective Ball bearing defective
7.	Ball screw	To give the linear motion to the frit tank	Ball damage Profile wear out Misalignment
8.	Solenoid valve	To give the compressed air blow	Plunger stuck Air leakage Coil burnt out Wire broken
9.	Servo motor	To give the rotation to ball screw in x and y axes	Winding burnt out Bearing defective Cable damage Encoder failure Techogenerator failure Relay failure
10.	Air cylinder	To give the motion to the	Air leakage

		moving parts	Piston seal damage
			Air connector defective

11.	Micro Switch	To give the signal to the control panel	Defective Malfunctioning
12.	Limit Switch	To give the signal to the control panel	Improper adjustment Arm broken Wire broken Defective
13.	Toggle switch	To switch on and off the frit tank agitator	Broken Loose Wire broken
14.	Gauging roller	To give the position to the funnel	Play Jammed Wear out
15	Sensor	To give the signal to the control panel	Wire broken Defective Disturb

4.6 CAUSE AND EFFECT DIAGRAM

The cause and effect diagrams of system functions and functional failures are shown in Fig. 4.8 – 4.12.

4.6.1 FUNNEL CARRY AND LIFTING SYSTEM

Fig. 4.8 represents cause and effect diagram of funnel carry and lifting system. The various components of this system are:

- **Reed Switch**

- **Solenoid Valve**

- **Funnel Holding Device**

- **Air Cylinder**

Maintenance problems of reed switch includes broken wire, defective, disturb.

If this type of problem occurs the signal will not go to NC controller and machine will not run.

Solenoid valve includes air leakage, wire broken, coil burnt out, plunger stuck. If this type of problem occurs the solenoid will not function properly, as a result air cylinder will not function and funnel carry and lifting system will not run.
Funnel holding device includes the nut loose, neck chuck plate wear out, neck clamp broken. If this type of problem occurs, the funnel will not hold properly as a result frit glass coating will disturb.
Air cylinder includes the piston seal damage, air leakage, air connector defective. If this type of problem occurs the cylinder will not function properly and funnel carry and lifting system will not run.

4.6.2 FUNNEL STOPPER SYSTEM

Figure 4.9 represents, cause and effect diagram of funnel stopper system. The various components of this system are:

- **Solenoid Valve**

- **Stopper Plate**

- **Sensor**

- **Air Cylinder**

Maintenance problems of solenoid valve includes plunger stuck, coil burnt out, air leakage, wire broken. In this type of problem solenoid valve will not operate as a result air cylinder will not function and stopper will not move.

Stopper plate includes plates loose, stripe wear out. If this type of problem occurs the funnel will not adjust properly by funnel stopper system as a result frit glass coating will disturb.

If sensor is defective, disturb, the signal will not go to NC controller and the machine will not run.

Air cylinder includes piston seal damage, air leakage, air connector defective. If this type of problem occurs the cylinder will not move as a result funnel stopper will not function.

4.6.3 FUNNEL GAUGING SYSTEM

Figure 4.10 represents cause and effect diagram of funnel gauging system.
The various components of this system are:

- **Gauging Roller**

- **Solenoid Valve**

- **Micro Switch**

- **Air Cylinder**

Maintenance problems of gauging roller include nut loose, play in roller, roller wear out, roller jammed. If this type of problem occurs in rollers the funnel will not hold properly by rollers as a result frit glass coating will disturb.

Solenoid valve includes plunger stuck, coil burnt out, wire broken, air leakage If this type of problem occurs solenoid valve will not operate properly as a result air cylinder will not function and gauging system will not move.

In case of micro switch defective or malfunctioning the signal will not go to NC controller and gauging system will not run.

Air cylinder includes piston seal damage, air leakage, and air connector defective. If this type of problem occurs the cylinder will not move as a result funnel-gauging system will not function.

4.6.4 AXES DRIVE SYSTEM

Figure 4.11 represents cause and effect diagram of axes drive system. The various components of this system are:

- **Ball Screw**

- **Limit Switch**

- **Servo Motor**

Maintenance problems of ball screw include profile worn-out, misalignment, and ball damage. If this type of problem occurs the frit glass tank unit motion will disturb as a result frit glass coating on the seal edge coating of the funnel will disturb.

If the limit switch is defective the signal will not go to NC controller and machine will not function properly. In case of limit switch disturb the axes drive system will over travel.

Servomotor includes bearing defective, winding burnt out, cable damage, encoder failure, techogenerator failure, relay failure. In case of winding burnt out, relay failure, cable damage, the servo motor will not run. In case of bearing defective the motor will make abnormal sound. In case of techogenerator and encoder failure, feed back will not be given to NC controller as a result the motor speed will be high.

In case of sensor defective, disturb, wire broken the signal will not go to NC Controller and the machine will not run.

4.6.5 FRIT GLASS TANK UNIT

Figure 4.12 represent cause and effect diagram of frit glass tank unit. The various components of the system are:

- **Shaft and Blade**
- **Toggle Switch**
- **Motor**
- **Coupling**

Maintenance problems of shaft and blade include screw loose, blade damage, shaft bend, ring bend, blade bend, shaft wear out. If this type of problem occurs the application of frit glass coating will not be uniform.

Toggle switch includes wire broken, contact loose or broken. In case of toggle switch broken the motor can not be switched on or switched off. In case of contact loose the motor will not run regularly, it may stop also as a result frit glass coating will disturb. In case of broken wire, motor will not run.

Motor includes winding burnt out, bearing defective, cable damage, slip in gears. In case of winding burnt out and cable damage the motor will not run. If there is bearing defective case the motor will make abnormal sound.

In case of slip in gears motor will not run uniformly.

Coupling includes misalignment, wear out, screw loose. If this type of problem occurs, the motor will not rotate the shaft properly.

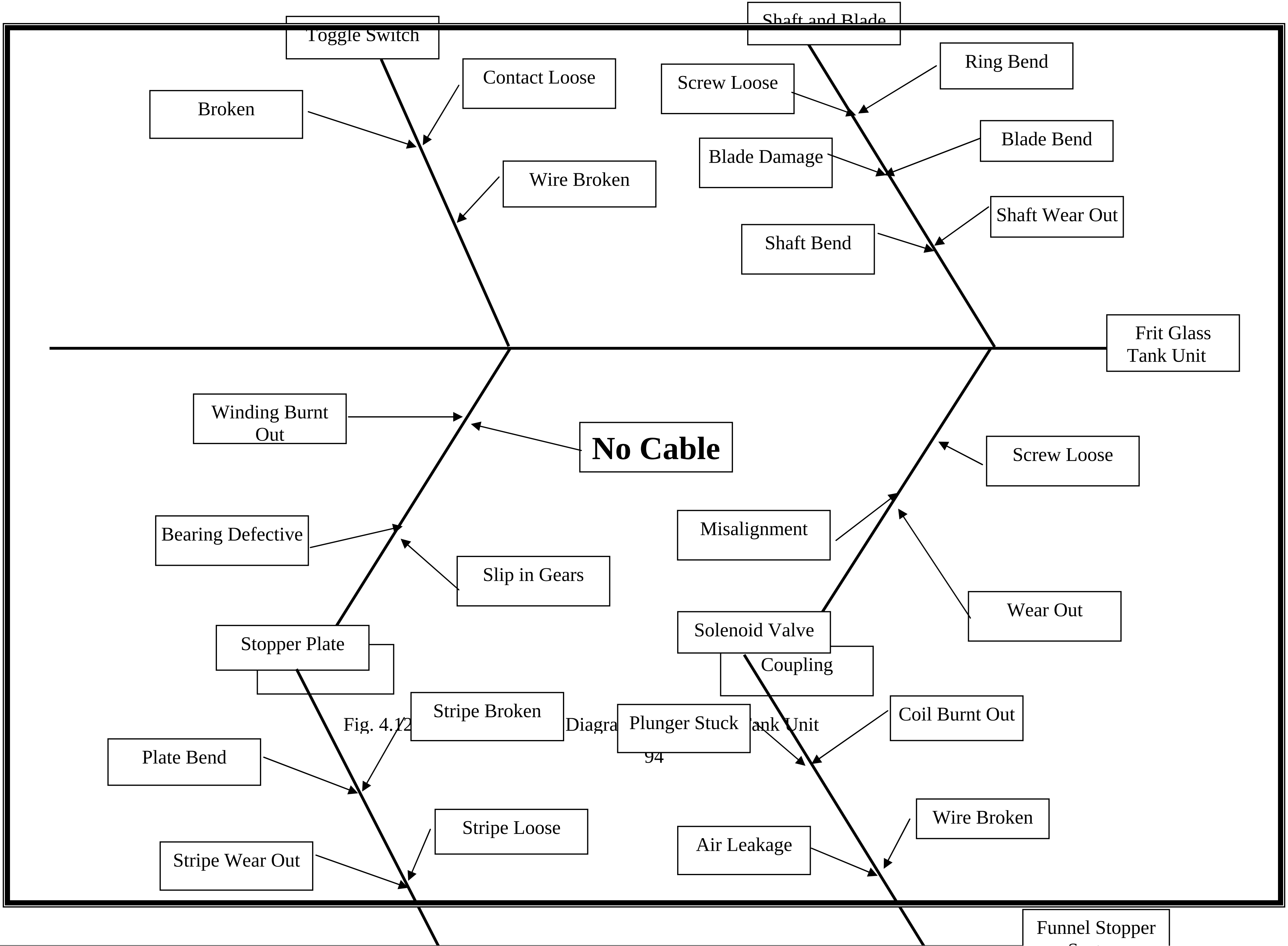
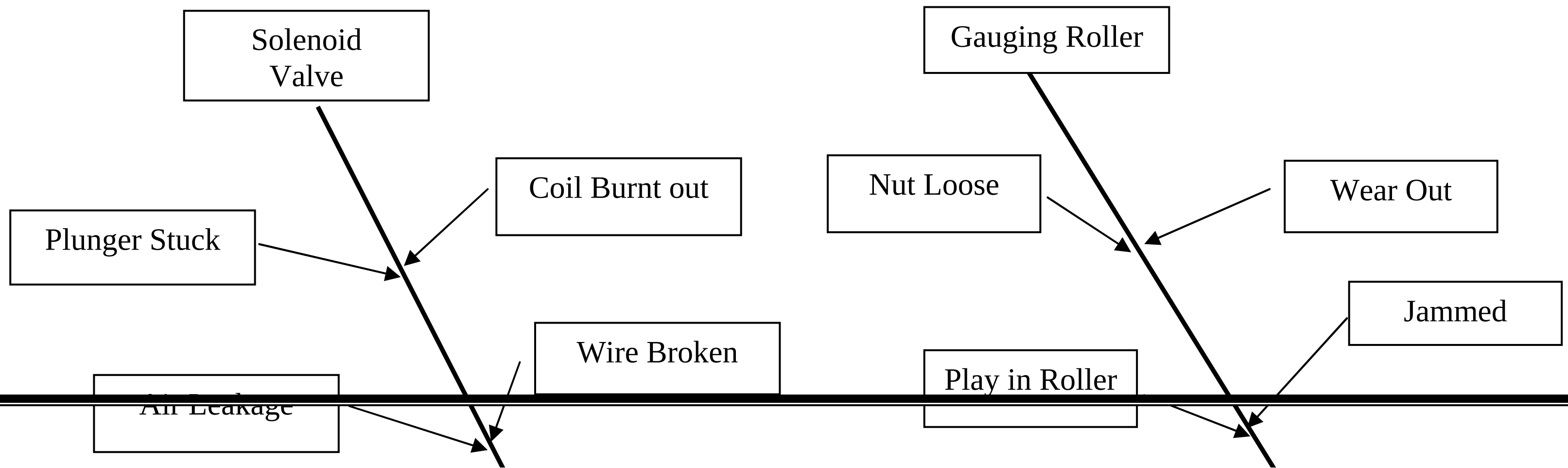
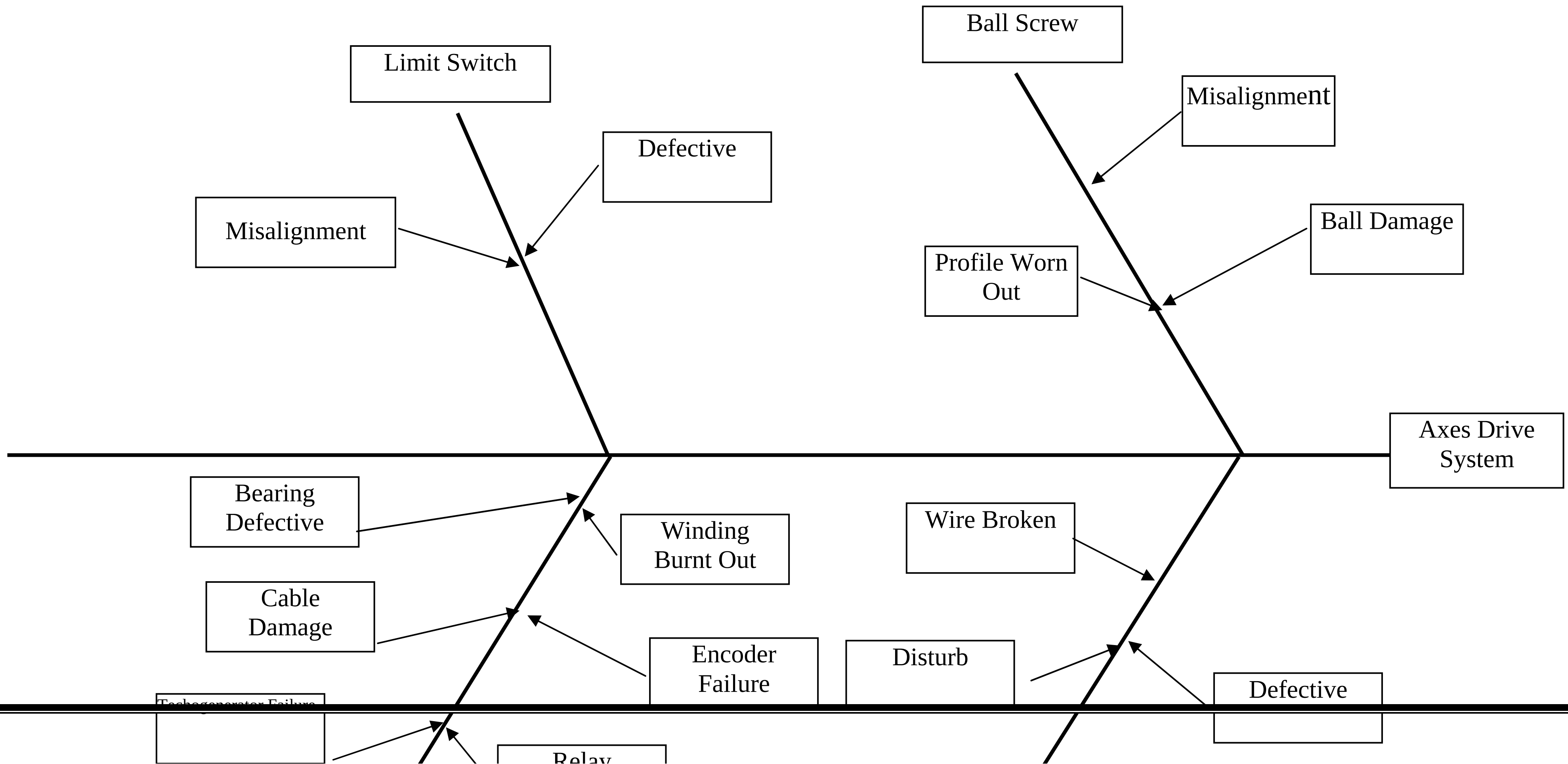
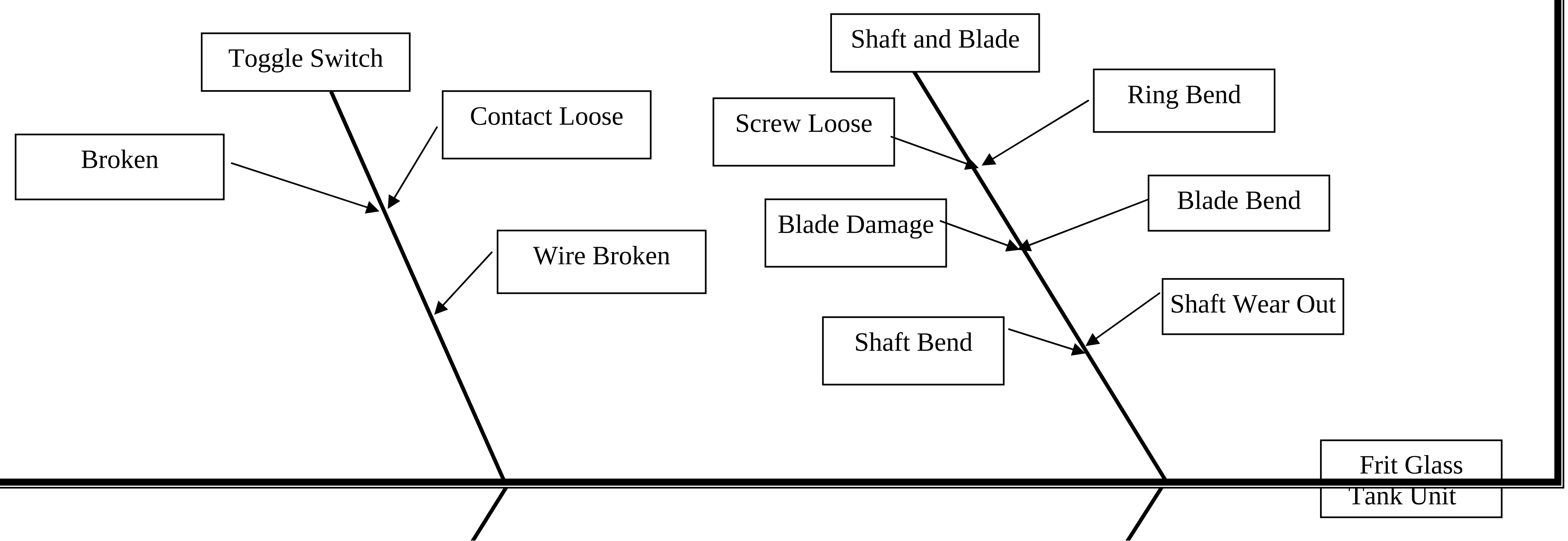


Fig. 4.12 ... Diagra... ank Unit


Solenoid Valve
Coil Burnt out
Plunger Stuck
Wire Broken
Gauging Roller
Nut Loose
Wear Out
Jammed
Play in Roller


Limit Switch
Defective
Misalignment
Ball Screw
Misalignment
Ball Damage
Profile Worn Out
Axes Drive System
Bearing Defective
Winding Burnt Out
Cable Damage
Encoder Failure
Wire Broken
Disturb
Defective
Relay



Toggle Switch
Broken
Contact Loose
Wire Broken
Shaft and Blade
Screw Loose
Ring Bend
Blade Damage
Blade Bend
Shaft Bend
Shaft Wear Out
Frit Glass
Tank Unit

4.7 FAILURE MODE AND EFFECT ANALYSIS (FMEA)

Failure mode effect analysis has been carried out to identify the equipment, which can play role in creation of functional failure. It is necessary to realize the various modes of failures, their effects at component level, assembly level and system level for 'detailed analysis' keeping in view the safety of a personnel, and environmental impact, m/c availability, product quality. FMEA has been carried out on funnel carrying and lifting system, stopper system, gauging system, axes drive system, and frit glass tank unit The FMEA analysis of different systems of NC m/c is shown in the tables 4.2 – 4.6. Table 4.2 Indicates the FMEA of Funnel Carry and Lifting System. It has been noticed that total time taken to replace the air cylinder is very high as compared to the frequency of the breakdown. Table 4.3 Indicates the FMEA of Funnel Stopper System. It has been noticed that total time taken to replace the air cylinder and stopper is very high in comparison of frequency. It shows the non-availability of air cylinder. Table 4.4 Indicates the FMEA of Funnel Gauging System . It has been noticed that the total time taken to rectify the problem due to play in rollers is very high as compared to its frequency. Table 4.5 Indicate the FMEA of Axes Drive System It has been noticed that the frequency coating disturb is very high. It has analyzed that the frit coating depends on different parameters. Table 4.6 Indicates the FMEA of Frit Glass Tank Unit. It has been noticed that total time taken for coupling and shaft replacement is high as compared to frequency of failure. The down time increase due to non-availability of spare parts. The table 4.7 indicates the trends of the breakdown data showing total number of frequency, down time and their relative percentage for each assembly.

TABLE 4.2 FMEA OF FUNNEL CARRY AND LIFTING SYSTEM

Function	Failure Mode	Possible Cause	Maintenance Action	Frequency	Down Time (Minutes)
To carry and lift the funnel according to operation requirement	Funnel not moving forward	Air cylinder defective	Replaced	1	220
		Reed switch broken	Replaced	1	25
	Funnel not moving upward	Air cylinder defective	Replaced	2	985
		Reed switch defective	Replaced	1	60
		Reed switch loose	Tighten	3	65
		Reed switch malfunctioning	Replaced	1	30
	Funnel holding device not functioning	Screw broken	Replaced	1	60
		Funnel neck clamp broken	New made and changed	1	115
Total				11	1560

The failure modes of this system are:

- Funnel not moving forward
- Funnel not moving upward
- Funnel holding device not functioning

The possible causes of these are, air cylinder defective, reed switch broken, read switch defective, reed switch malfunctioning, screw broken, reed switch loose, funnel neck clamp broken. Maintenance action was taken to tight the reed switch in case of loose and new clamp made and replaced in case of clamp broken. In other cases except these two cases components were replaced.

TABLE 4.3 FMEA OF FUNNEL STOPPER SYSTEM

Function	Failure Mode	Possible Cause	Maintenance Action	Frequency	Down Time (Minutes
stop the nnel cording to eration	Stopper not functioning	Air Cylinder Defective	Replaced	2	545
		Air cylinder not moving	Air pressure adjusted	1	20
		Stopper plate stripe	Replaced		

quirement		broken		2	75
	Frit glass coating wiped off	Sensor disturb Stopper plate screw loose Stopper plate bend	Adjusted Tighten Replaced	2 1 2	45 40 600
Total				10	1325

The failure modes of this system are:

- Funnel stopper not functioning
- Frit glass coating wiped off

The possible causes of these are, air cylinder defective, stopper plate stripe broken, stopper plate bend. In all these cases the maintenance department replaced the components. In case of air cylinder not moving, air pressure adjusted and in case of sensor disturb, maintenance department did the adjustment of sensor.

TABLE 4.4 FMEA OF FUNNEL GAUGING SYSTEM

Function	**Failure Mode**	**Possible Cause**	**Maintenance Action**	Frequency	**Down Time (Minutes)**
To hold and give the	Funnel slippage in gauging	Arm loose Gauging pin broken	Tighten New made and	1 1	50 130

position to the funnel	operation		Replaced		
	Gauging unit not functioning	Roller jammed	Replaced	2	195
		Roller wear out	Replaced	2	230
		Play in Rollers	Replaced	3	675
		Micro switch defective	Replaced	3	135
Total				12	1415

The failure modes of this system are:

- Funnel slippage in gauging operation
- Gauging unit not functioning

The possible causes of these are roller jammed, roller wear out, play in rollers, micro switch defective, in all theses cases the maintenance department replaced the components. In case of arm loose, arm was tighten and in case of gauging pin broken, new pin was made and replaced by the maintenance department.

TABLE 4.5 FMEA OF AXES DRIVE SYSTEM

Function	**Failure Mode**	**Possible Cause**	**Maintenance Action**	Frequency	**Down Time (Minutes)**

give the otion to glas tank it in x and y es	Frit coating disturb	Programming disturb	Programming done	20	2135
		Play in x axis ball screw	Replaced	1	390
	X axis drive problem	x axis over travel	Limit switch Adjusted	2	1200
			Motor replaced	2	1700
	Y axis problem drive	Bevel gear damage	Replaced	1	100
		Bearing defective	Replaced	2	105
		Motor defective	Replaced	1	160
		Bearing defective	Replaced	1	70
		Motor cable loose	Cable opened and tighten	1	240
	M/c not running	Power fluctuation	Voltage adjusted	8	795
		Glass fuse blown out	Replace	1	45
		PLC program disturb	Programming done	1	45
		PLC alarm and m/c stop	Power supply card Replaced	1	120
Total				42	7105

The failure modes of this system are:

- Frit glass coating disturb

- X axis drive problem
- Y axis drive problem
- M/c not running

The possible causes of these are, play in x axis ball screw, bevel gear damage, bearing defective, motor defective, glass fuse blown out. In all these cases maintenance department replaced components. In case of programming disturb, programming was done. In case of x axis over travel limit switch was adjusted and motor also replaced. In case of motor cable loose, cable opened and tightened. Voltage adjusted in case of power fluctuation. In machine stop case power supply card was replaced.

TABLE 4.6 FMEA OF FRIT GLASS TANK UNIT

nction	Failure Mode	**Possible Cause**	**Maintenance Action**	**Frequency**	**Down Time (Minutes)**
keep frit ss ry	Agitator not rotating	Shaft wear out	Replaced and fitted	1	210
		Shaft end damage	New made and fitted	1	315
		Coupling damage	New made and fitted	2	280
		Coupling screw loose	Drillig and tapping	2	125
		Gear box slip	Gear replaced	1	140
		Motor wire broken	Connected	2	25
		Motor regulator defective	Replaced	2	125
		Motor connector open	Connected	1	30
		Motor overheated	Replaced	1	120
		Agitator ring bend	Replaced	1	65
		Agitator blade bend	Replaced	1	115
	Total			15	1550

The failure mode of this system is:

- Agitator not rotating

The possible causes of this system are shaft wear out, gear box slip, motor regulator defective, motor over heated, agitator ring bend, agitator blade bend. In all the cases maintenance department replaced the components. In case of shaft end damage and coupling damage, new made and fitted. In case of coupling screw loose, drilling and tapping was done to tight the screw. In case of motor wire broken and connector open, connection was done.

TABLE 4.7 FAILURE TREND OF ASSEMBLIES OF N.C. FRIT COATING M/C

ASSEMBLY	**FAULTS**		**BREAKDOWN TIME**	
	No.	**Relative %**	**Minutes**	**Relative %**
Funnel Carry and Lifting System	**11**	**12.22**	**1560**	**12.04**
Funnel Stopper System	**10**	**11.11**	**1325**	**10.23**
Funnel Gauging System	**12**	**13.33**	**1415**	**10.92**
Axes Drive System	**42**	**46.67**	**7105**	**54.84**
Frit Tank Unit	**15**	**16.67**	**1550**	**11.97**
Total	**90**	**100.00**	**12955**	**100.0**

As indicated in the table 4.7 the assemblies can be enlisted in order of higher frequency of failures.

1. **Axes Drive System.**
2. **Frit Tank Unit**
3. **Funnel Gauging System**
4. **Funnel Carry and Lifting System**
5. **Funnel Stopper System**

4.8 LOGIC TREE ANALYSIS (LTA)

Logic tree analysis is carried out to identify the possible basic causes of the failure of a system or assembly. Using LTA, the causal relationship between the different components of the assembly can be realized which helps in concluding specific system failure mode. The failure of the machine is related to the failure of assembly, which in turn related to the failures of components i.e. failure of solenoid valve due to coil burnt out causes the failure of funnel stopper system and ultimately leading to m/c failure. The Logic Tree Analysis format is given at figure 4.13 and LTA for each assembly have been carried out, considering the top event as "assembly not functioning," these are shown in the figures 4.14 – 4.18.

System Level Failure
Or
Unsafe Condition

Basic

Event

Undevelope
d Event

Inhibit
Gate

Conditional
Event

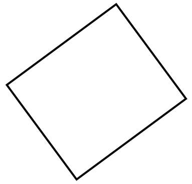
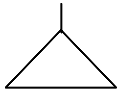
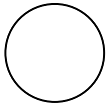
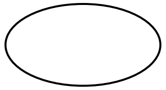
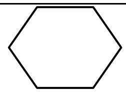
Event

And

Basic

Event

Description of Symbols

	COMBINATION EVENT: An event resulting from the combination of basic faults and / or conditions which can be developed further		UNDEVELOPED EVENT: A fault not developed further because of lack of information, time or value in doing so.
	BASIC EVENT: It depicts very specific fault and requires no further development		TRANSFERRED EVENT: Symbols used for in and out from the logic tree.
	AND GATE: The output events occur only when all of the input events are present		OR GATE: The output events when one or more of the input events are present.
	INHIBIT GATE: Similar to AND gate, however used to include application of a conditional event.		

4.9 TASKS SELECTION

The objective of this step is to reduce the consequences of failure, longer down time of those m/c parts, which are potentially critical with respect to failure mode and effect analysis step. For this machine, study has been carried out with respect to FMEA and a daily inspection check sheet is developed for reducing the consequences of failure and longer down time. The check sheets are given in tables 4.8 – 4.9.

TABLE 4.8 NC FRIT GLASS COATING MACHINE

DAILY CHECK SHEET

Month:

Activity	Item to be Check	What to Check	How to Check	Standard Value	Date	
					1	2
					Actual Value	Actual Value
Cleaning	1) Outside & inside area of m/c	Cleanliness	Visual	Clean		
	2) Top plate of the machine	Cleanliness	Visual	Clean		
	3) Dropped frit glass on parts	Cleanliness	Visual	Clean		
Lubrication	Guide rods of funnel lifting and gauging units	Cleanliness & Lub.	Visual	Clean and Lub.		
Inspection	1) Emergency stop push button	Working condition	Operator	Machine stop		
	2) Front & rear door status	Opening	Visual	Closed doors		
	3) Air leakages	Leakage	Visual & hear	No air blow outside		
	4) Agitator	Rotation	Visual	Uniform rotation		
	5) Abnormal sound	Abnormal sound	Hearing	No abnormal sound		

Done By:	Machine Operator:		
	Signature:		

Note: Put tick mark in actual value column only if actual value is equal to standard value.

TABLE 4.9 NC FRIT GLASS COATING MACHINE

DAILY CHECK SHEET

Month:

Activity	Item to be Check	What to Check	How to Check	Standard Value	Date 1	Date 2
					Actual Value	Actual Value
Inspection	Oil level in FRL unit	Level	Indicator	Between H&L		
	X & Y axes Ball screws	Sound	Hearing	No sound		
	Funnel gauging unit	Centering	Visual	No funnel tilt		
	Gauging rollers	Outside surface	Visual	No burrs & wear out		
	Air cylinders	Smooth working	Visual	Smooth running		
	Funnel clamp neck jaws	Working condition	Visual	No cracks / broken		
	Air pressure	Pressure	Pressure gauge	H=<5 kg/cm^2 L=>4 kg/cm^2		
Done By:		Technician: Signature:				

Note: Put tick mark in actual value column only if actual value is equal to standard value.

4.9.1 EQUIPMENT EFFECTIVENESS

The overall equipment effectiveness depends on following three factors:

1. **Availability:** The operating rate tells us what percentage of time equipment is actually running when we need it. This is expressed in the following calculation:

$$\text{Availability (operating rate)} = \frac{\text{Loading time} - \text{Downtime}}{\text{Loading time}} \times 100$$

In this case, loading time is the daily (or monthly) time available for operation minus all forms of scheduled stops-breaks in the production schedule, stoppages for routine maintenance, morning meeting, and so on. Downtime is the total time taken for unscheduled stoppages such as breakdowns, retooling, and adjustments. Loading time minus downtime yields the operation time.

2. **Performance Rate:** The performance rate is based on the operating speed rate and the net operating time. The operating speed rate tells us how fast a machine is running compared to its ideal or designed speed. When the performance rate shows a speed reduction, it reflects a hidden loss. The operating speed can be calculated as:

$$\text{Operating speed rate} = \frac{\text{Ideal cycle time}}{\text{Actual cycle time}} \times 100$$

Net operating time is the time during which equipment is being operated at a constant speed within a specified period. Here the issue is not how fasts the equipment is operating relative to the ideal speed, but whether it is running at a constant speed without interruption. Net operating time can therefore be used to calculate loss due to idling and minor stoppages, or other problems not usually mentioned in the daily log.

$$\text{Net operating rate} = \frac{\text{Output x Actual cycle time}}{\text{Loading time} - \text{Downtime}} \times 100$$

The performance rate will be calculated as

Performance rate = Net operating rate x Operating speed rate

$$= \frac{\text{Processed amount x Actual cycle time}}{\textit{Operating time}} \times \frac{\text{Ideal cycle time}}{\textit{Actual cycle time}}$$

$$= \frac{\text{Processed amount x Ideal cycle time}}{\text{Operating time}}$$

3. **Quality Rate:** The quality rates tell us at what percentage the good product is produced, keeping in view all the quality defects.

Therefore overall equipment effectiveness (OEE) is as follows:

OEE = Availability x Performance rate x Quality rate

The Overall Equipment Effectiveness (OEE) of NC Frit Glass Coating Machine:

Loading time = 791 days

= 791 x 24 x 60

= 1139040 minutes

Breakdown time = 12955 minutes

Since m/c stops 72 minutes for frit glass filling in 1 day.

So downtime due to frit filling

= 791 x 72

= 56952 minutes

Total down time = Breakdown time + Frit filling time

$= 12955 + 56952$

$= 69907$ minutes

$$\text{(i) Availability} = \frac{\text{Loading time — Downtime}}{\text{Loading time}} \times 100$$

$$= \frac{1139040 - 69907}{1139040} \times 100$$

$$= \frac{1069133}{1139040} \times 100 = 93.86\%$$

(ii) Performance Rate

Ideal cycle time = 18 second

Actual cycle time = 28 second

$$\text{Operating speed rate} = \frac{\text{Ideal cycle time}}{\text{Actual cycle time}} \times 100$$

$$= \frac{18 \text{ second}}{28 \text{ second}} \times 100$$

$$= 64.29\ \%$$

Average production per day = 2250 funnels

Total funnels produced = 791 x 2250 = 1779750 Nos

$$\text{Net operating rate} = \frac{\text{Output x Actual cycle time}}{\text{Loading time — Downtime}} \times 100$$

$$= \frac{1779750 \text{ x } 28 \text{ second}}{(1139040\text{-}69907) \text{ x } 60 \text{ second}} \times 100$$

$$= \frac{49833000}{64147980} \times 100$$

$$= 77.68\%$$

Performance Rate = Net operating rate x Operating speed rate

= .7768x.6429x 100 = 49.94 %

(iii) Quality Rate

The rate of quality product is 99%

Then the overall equipment effectiveness will be as follows:

OEE = Availability x Performance rate x Quality rate

= .9386x.4994 x 0.99 x 100

= 46.40%

(iv) Utilization $= \dfrac{\text{Scheduled time}}{\text{Calendar time}}$

$$= \frac{791 \text{ days}}{1095 \text{ days}} \times 100 = 72.24\ \%$$

(v) Productive capacity OEE x Utilization

0.4640 x 0.7224 x 100

= 33.52%

5.1 CONCLUSIONS

The maintenance of plant and equipment is an important aspect when the response to complex environment is given through the process rather than inventory. Reliability Centered Maintenance helps in improving the reliability of the equipment at lowest cost. In this project, the RCM methodology has been applied to NC Frit Glass Coating Machine of an electronics company, manufacturing colour picture tubes. The important techniques under RCM are Failure Mode and Effect Analysis, Logic Tree Analysis, Cause and Effect diagram. By applying these techniques the various activities along with schedule, responsibility is fixed so as improve reliability and to reduce the impact of the equipment. In this case study even though the availability of the equipment is 93.86 percent, the overall equipment effectiveness and productive capacity, when actually calculated are not even 50 percent, but an astonishingly low as 46.40 percent, and 33.52 percent respectively. The poor OEE and productive capacity is due to lower operating speed, poor net operating time, more down time of axes drive system and poor plant production schedule. The check sheets are developed for daily inspection of machine by operator and maintenance technician. The daily inspection of machine will definitely reduce the longer down time and consequences of failure.

5.2 SCOPE FOR FUTURE WORK

This study is carried out on only one machine of the large manufacturing line. To improve the productivity of the plant and the response to the customer, RCM should be applied at all the stages. The calculations and study suggests that the company should find ways to speed up equipment reduce the down time, consequences of failure and increase the quality rate. Maintenance department should conduct the preventive maintenance, proactive maintenance of the machine.

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