# UNIT 9 RELIABILITY, AVAILABILITY AND MAINTAINABILITY CONCEPTS

**Objectives**

After studying this unit, you should be able to:

- understand the concept of reliability, availability and maintainability,
- establish the relationship between reliability, availability and maintainability,
- measure reliability of the system having components in series and components in parallel,
- understand the factors affecting the maintainability and reliability.

**Structure**



## 9.1 INTRODUCTION

The term Reliability, Availability and Maintainability (RAM) is very important for the operational as well as maintenance personnel. The RAM of equipment effects the productivity of the manufacturing system. Reliability of a machine or equipment is the probability that the equipment will give failure free performance of its intended functions during that time. It is measured as Mean Time Between Failure (MTBF). It is the average time between two consecutive failures. When failure rate is fairly constant, it is reciprocal of the constant failure rate. The availability of machine or equipment is different from reliability. A machine or equipment may be highly reliable as the failure rate is negligible and it fails only one or two times in a given period. But availability may be very bad because once it fails it takes very long to repair. The time taken to repair is the concept of maintainability. It is a characteristics of design and installation which is expressed as the probability that an item will be restored to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources. Numerically it is calculated as the Mean Time To Repair (MTTR) which is defined as the statistical mean of the distribution of times to repair. The cumulation of active repair times during a given period of time divided by the total number of malfunctions during the same time interval. In this unit you will learn the concept, interrelationship and the ways to improve reliability, availability and maintainability.

## 9.2 RELIABILITY

Reliability is the probability of a product/equipment/process/system performing its intended function for a stated period of time under certain specified conditions. Four aspects of reliability are apparent from this definition.

- Reliability is a probability based concept. The numerical value of reliability is between 0 and 1.
- The functional performance of the product to meet certain stipulations. Product design will usually ensure development of a product that meets or exceeds the stipulated requirements.
- Reliability implies successful operation over a certain period of time.
- Operating or environmental conditions under which product use takes place are specified.

Reliability of an equipment having many parts is a complex phenomenon and to be examined carefully. Consider equipment with 500 parts all in series and reliability of each part is 99.5 %. The reliability of this equipment would be $(0.995)^{500}$, which comes out to an unexpected low value of 8%. No one would accept such equipment which has more than 92 % failure chances. Thus reliability is a function of complexity i.e. the number of components. The manufacturing of equipment and its repair method should be such that most of the parts have 100 % reliability.

Reliability engineering is concerned with identifying and isolating the parts which have less than 100 % reliability after having best manufacturing and repair methods. These parts need necessary corrective action. The need of reliability should be carefully assessed. The failure of one component doesn't always cause total failure of the equipment nor does the failure of one equipment always cause total failure of the project or mission (except project like space mission). Achieving total reliability is very costly and so the users in the industries often have to compromise and aim for the low chance of failure of the equipment. Equivalent emphasis is placed on early return back of the equipment after repair of any breakdown.

Reliability improvement is a continuous engineering process. It involves enormous amount of data collection, data analysis to find out the mode of failure and various stresses on the equipment. Production department using the equipment, maintenance department, the equipment manufacturer and the designer of the equipment are fed with this data for necessary actions to improve reliability. Pareto analysis is used to segregate critical components/parts which fail too frequently or which have greater impact on the availability of the equipment. This is also called 80 : 20 analysis, where 20 % of the parts account for 80 % of the failures.

At the design stage various approaches are used to enhance the reliability of the equipment. The most prevalent is use of over design. Using thicker material, stronger, better materials for light purpose equipment. This approach is highly inefficient from the cost perspective, as it increases the cost of equipment. Other approaches being used are simple and standardized components/ parts. Lesser the number of components, higher is the reliability. Standardized, proven components have higher reliability than tailor made special components.

Most products go through three distinct phases from product inception to wear out. *Figure 9.1* shows a typical Failure Rate curve for which failure rate is plotted as a function of time. This curve is also called bath tub curve because of its shape. The three distinct phases are:

**Debugging Phase :** This is also called infant mortality phase represents the failures due to initial problems.

**Chance Failure Phase :** In this phase failures occur randomly and independently. The failure rate in this phase is low and constant, and represent the useful life of the equipment.

**Wear Out Phase :** In this phase an increase in failure rate is observed as parts age and wear out.

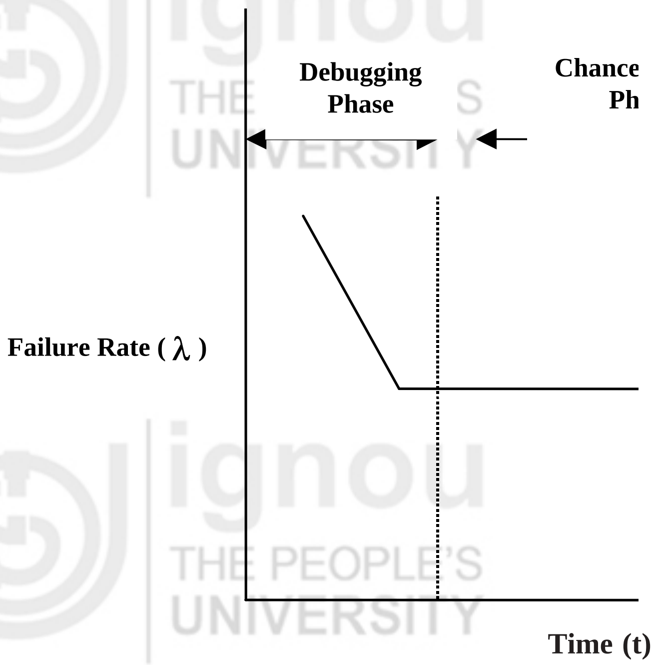



**Figure 9.1 : A Typical Life Cycle Curve**

The reliability of a machine or equipment is measured as Mean Time To Failure (MTTF). If $\lambda$ is the failure rate, then MTTF is expressed as

$$MTTF = 1/\lambda$$

MTTF is used for the equipment, which fails and cannot be repaired. They are replaced. Mean Time Between Failure (MTBF) is used for repairable components. The cases where the repair time is negligible, MTBF is same as MTTF.

For the chance failure phase, which represent the useful life of the equipment, the failure rate is constant. Thus exponential distribution can be used to describe the time to failure of the product for this phase. The probability density function of exponential distribution for time to failure is given by

$$f(t) = \lambda e^{-\lambda t} \qquad t \geq 0$$

Cumulative failure function at time t is given by

$$F(t) = \int_0^t \lambda e^{-\lambda t}\, dt$$

The reliability at time t, R(t) is the probability of the equipment lasting upto atleast time t is given by

$$R(t) = 1 - F(t)$$
$$= 1 - \int_0^t \lambda e^{-\lambda t}\, dt = e^{-\lambda t}$$

The failure rate function r(t) is given by the ratio of time to failure probability density function to the reliability function.

$$r(t) = f(t) / R(t)$$

The reliability parameters MTBF and MTTF are useful for the maintenance department to develop the wear out characteristics of the components and equipment. This analysis helps in developing better monitoring and preventive maintenance programs. The need of spare parts and standby equipment can also be estimated from the MTBF/ MTTF data. The production department can use the reliability data to estimate the down time of the equipment. In general, the effectiveness of an equipment is a function of reliability and availability of the equipment. The safety standard of the equipment are designed with the knowledge of reliability of components.

**Numerical**

An electronic component in a CNC Lathe machine has an exponential time to failure distribution with a failure rate of 8% per 1000 hours. What is the reliability of the component at 5000 hour? Find the mean time to failure:

The constant failure rate $\lambda$ is calculated as

$$\lambda = 0.08/ 1000 = 0.00008 \text{ per hour}$$

The reliability at 5000 hour is given as

$$R(t) = e^{-\lambda t} = e^{-(0.00008)(5000)} = e^{-0.4} = 0.6703$$

Mean Time to Failure

$$MTTF = 1/\lambda = 1/0.00008 = 12{,}500$$

hours

## 9.3 SYSTEM RELIABILITY

Most equipment and machines are made up of a number of components. The reliability of each component and the configuration of the system consisting of these components determine the system reliability. Although product design, manufacture and maintenance influence reliability, improving reliability is largely the domain of design. One common practice for increasing reliability is through redundancy in design that is placing components in parallel. As long as one component operates, system operates. System fails when all components in parallel fail.

**System with Components in Series**

Figure 9.2 shows three components A, B and C in series. For the system to operate, each component must operate. It is assumed that the components operate independent to each other. Failure of one component has no effect on the failure of any other component. The reliability ( R ) of this type of system with n components having reliability $r_1, r_2, r_3, ......r_n$ is given by

$$R = r_1 \times r_2 \times r_3 \times .....\times r_n \quad .....$$

The system reliability decreases as the number of components in series increases. Product designs with fewer numbers of components are more reliable.

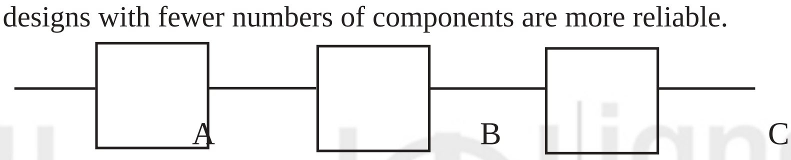



**Figure 9.2 : System with components in series**

**Numerical**

A module of an aircraft has 100 components each with a reliability of 0.999. Find the reliability of the module. If the number of components is reduced to 50, how much is the improvement in reliability.

**Solution**

The system reliability of the module is

$$R = (0.999)^{100} = 0.9047$$

Thus even with a very high reliability of components, the system reliability is only 90%.When the number of components are reduced to 50, The reliability of the module is 0.9512.

Improvement in reliability = 5.13%

**Numerical**

A module of an automatic machine has 10 components in series. Each component has an exponential time to failure distribution with a constant failure rate of 0.05 per 4000 hours. What is the reliability of each component and the module after 2000 hours of operation? What is the mean time to failure of the module?

**Solution**

The failure rate of each component ( $\lambda$ ) is given by

$$\lambda = 0.05 / 4000 = 1.25 \times 10^{-5} \text{ per hour.}$$

The reliability ( r )of each component after 2000 hours of operation:

$$r = e^{-\lambda t} = e^{-0.0000125\ (2000)} = 0.975$$

The reliability ( R )of the module is given by

$$R = r^{10} = (0.975)^{10} = 0.779$$

The mean time to failure of the module $= 1/n\,\lambda$

$$= \frac{1}{10} \times \frac{1}{(1.25 \times 10^{-5})} = 8000 \text{ Hrs}$$

**System with Components in Parallel**

The system with redundant components has higher reliability. In this the system operates as long as atleast one of the components operates. Figure 9.3 shows three components X, Y, and Z in parallel. The system will fail when all three components X, Y, and Z fail. For a system having n components in parallel, with reliability of r, the system reliability is given by

$$R = 1 - \Pi\,(1 - r_i) = 1 - [(1 - r_x)\,(1 - r_y)\,(1 - r_z)]$$

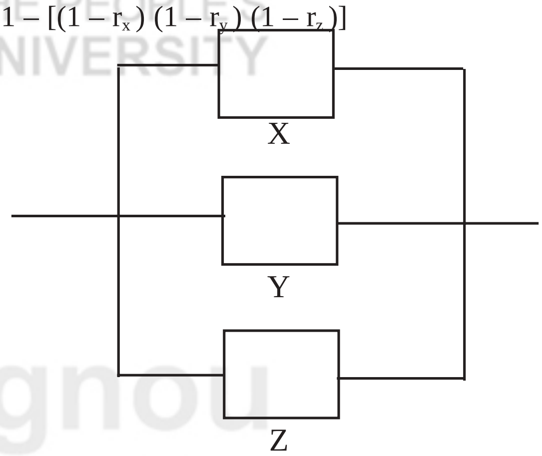



**Figure 9.3 : System with components in parallel**

**Numerical**

Three components X, Y and Z are in parallel, The reliability of X, Y and Z are 0.95, 0.92 and 0.90 respectively. Find the reliability of the system.

**Solution**

The reliability ( R ) of the system is given by

R = 1– [(1– 0.95) (1– 0.92) (1– 0.90)

= 1– 0.0004 = 9996

## 9.4 MAINTAINABILITY

Maintainability is an obscure concept unless derived from and related to the purpose of the system or equipment. It must be derived mathematically before it can be used as significant system specification. After making these decisions, business decisions can be made regarding allocation of budgets and resources to design, development and maintenance as well as reliability and performance. Alternative system designs and configurations of different module sizes have alternative reliability and maintainability values and require different resources for the maintenance department. One of the important considerations in design is maintenance free design. Maintainability may be given less importance in one shot applications like missile and rocket propulsion, where reliability is highly important. But in most of the general industrial machines and equipment maintainability has to be given due consideration.

The maintainability is the combined qualitative and quantitative characteristics of material design and installation which enable the accomplishment of operational objectives with minimum expenditure including manpower, personnel skill, test equipment, technical data and facilities under operational environmental conditions in which scheduled and unscheduled maintenance will be performed. The improvement in maintainability of machine or equipment requires that the procuring activity should specify an equipment repair time in the detailed equipment or system specification. The design of equipment or system should be such that the geometric mean of all active repair time intervals required to repair independent failures shall not exceed the specific equipment repair time. Compliance of this requirement needs to be verified in the final design stage and in the procurement and operational stage. Some of the quantitative measures of requirement are:

- Maintenance man-hours per 100 machine running hours.
- Turnaround time required for returning the machine to an operationally ready condition.
- Percentages of components/ modules, which can be down for maintenance and still permit the attainment of the operational requirement.

The another aspect of maintainability is its consequences and the intensity of consequence. The five consequences can be down time, maintenance time, logistics requirements, equipment damage and personnel injury.

## 9.5 ELEMENTS OF MAINTAINABILITY

The improvement in maintainability is an important aspect of design and maintenance department. The various policies and decisions related to maintainability can be classified as:

a) design decisions

b) maintenance policies

c) technician requirement

The various elements of design decisions, maintenance policies and technical requirements are given in *Table 9.1*.

The combined effect of these three affects the various components of down time *viz*.,

i) Detection Time
ii) Diagnosis Time
iii) Correction Time
iv) Verification Time

**Table 9.1: Elements of Maintainability**

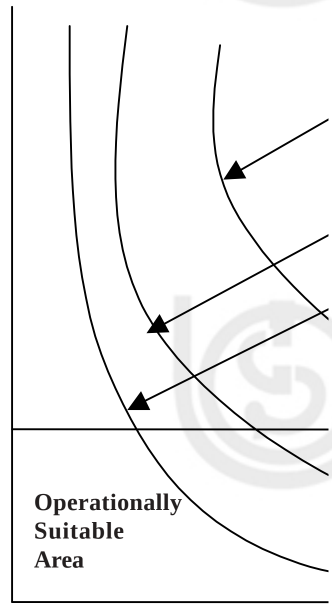
| Group | Elements |
|---|---|
| A) **Design Decisions** | • Modular design of equipment<br>• Standard fastners<br>• Limited variety and sizes of fastners<br>• Interchangeability of components<br>• Good approach to detect and correct fault<br>• Quick opening arrangement<br>• Use of components with fail safe measures<br>• Better labeling and colour coding to prevent wrong connections |
| B) **Maintenance Policies** | • Repair vs. Discard<br>• Replacement policy<br>• Spare parts policy<br>• Condition monitoring<br>• Proper instruments for monitoring of system<br>• Use of torque wrenches and other efficient tools<br>• Use of crane and other lifting mechanisms for heavy components |
| C) **Technician Requirements** | • Education, experience, aptitude of technicians<br>• Training to technicians to analyse tasks, understand procedures.<br>• Compatibility of man and system |

## 9.6 AVAILABILITY

Reliability and maintainability jointly affect the equipment availability for the user. A highly reliable system, which fails very rarely, may take a long time to repair and re-commission, once it fails. Thus the availability of highly reliable equipment is reduced by its poor maintainability. Similarly, equipment may have good maintainability, but if its reliability is poor and fail frequently can result in poor availability.

At the design stage, the operational availability requirements can be converted to reliability and maintainability requirements within the constraints of the mission. Several alternative combinations of reliability and maintainability can be obtained for any given availability level (*Figure 9.4*). In the working of a machine for 100 hours,

**Mean Time To Repair (*Maintainability*)**




**Failures Per Period (*Reliability*)**

**Figure 9.4 : Availability of Equipment as function of Reliability and Maintainability**

the availability of 95% can be achieved by five failures each having a down time of one hour. Alternatively, failure of 10 with each down time of 30 minutes will give availability of 95%. Both these rates may be tolerable from the operational view point. Other alternatives giving 95 % availability, like 100 failures each with down time of 3 minutes may not be operationally suitable. From the operationally suitable alternatives, total cost of the alternatives should be investigated. Total cost of improving availability consists of cost of improving reliability and cost of improving maintainability. Reliability improvement is one time investment cost, which then result in recurring savings in maintenance cost over the life of the equipment. The need for cost minimization among reliability improvement and maintainability improvement alternatives that meet operational requirements leads to trade off studies between reliability and maintainability.

Attaining a desired level of system availability requires a complex process involving many resources of which system reliability and maintainability requirements are generalized characteristics describing system performance during a time period. The system availability A can be described as follows, assuming steady state conditions.

$$A = [MTBF / (MTBF + MTR + MTWS)]$$

Where

A Availability of the system,

MTBF Mean Time Between Failure

MTR Mean Time to Repair

MTWS Mean Time Waiting for Spares, reflecting supply

Availability can also be expressed as input-output function:

$$A = f (R, M, S)$$

Where

A Availability

R Reliability

M Maintainability

S Supply Effectiveness

Most decisions involving resource use in system design are developed under a condition where the availability function appears as follow:

$$A = g\,(R, M / S, P, C, X_1, X_2, \ldots\ldots, X_n)$$

Where in addition to the earlier defined variables:

P System engineering performance requirements

C General system constraints such as cost, size, time, weight, etc.

$X_1, X_2, \ldots\ldots, X_n$ Unspecified factors such as vulnerability, environment, technician competence etc.

The relation above shows that reliability and maintainability are the product of resource combination, which then result in system availability.

## 9.7 SUMMARY

With the increase in complexity and the opportunity cost of non- availability of equipment when required, the understanding of the concepts of reliability, maintainability and availability of equipment is becoming more and more important. Reliability is the probability of a product/ equipment/ process/ system performing its intended function for a stated period of time under certain specified conditions, whereas maintainability is concerned with the bringing back a failed equipment to its operable condition with in a specific down time. Reliability and maintainability together decide the availability of the equipment. It is possible that equipment with high reliability may have low availability due to poor maintainability and vice a versa. The various elements under design decisions, maintenance policies and technician requirement affect the reliability, maintainability and availability.

In this unit, you have studied the concepts of reliability, maintainability and availability. With the help of numericals, you also know how to calculate reliability as mean time to failure. The various elements to improve reliability and maintainability are also presented.

## 9.8 KEY WORDS

**Availability :** The probability that a system or equipment when used under stated conditions, without consideration for any schedule or preventive maintenance in an ideal support environment, shall operate satisfactoily at any given time.

**Durability:** Durability is defined mainly by the length of the active life or endurance of the product under given working conditions.

**Maintainability:** Maintainability is a characteristic of design and installation which is expressed as the probability that an item will be restored to specific conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources.

**Maintenance:** All actions necessary for retaining an item in or restoring to a serviceable condition. Maintenance includes servicing, repair, modification, overhaul, inspection and condition determination.

**Mean Time Between Failure:** Mean time between failure is the average time between two consecutive failures. When failure rate is fairly constant, it is reciprocal of the constant failure rate.

**Mean Time to Repair:** The statistical mean of the distribution of times to repair. The cummulation of active repair times during a given period of time divided by the total number of malfunctions during the same time interval.

**Repair:** The process of returning an item to a specified condition including preparation, fault location, item procurement, fault correction, adjustment and calibration and final test.

**Repairability:** The capability of an item to be repaired.

**Reliability:** The reliability of component/equipment/system can be defined as the probability that it will perform a specific function, under specified conditions for a specified period of time.

## 9.9 SELF ASSESSMENT QUESTIONS

1) Briefly describe the concept of reliability, maintainability and availability.
2) 100 % reliability of all the components of a machine or equipment is not always aimed to achieve. Why?
3) Explain procedures that might improve the reliability of a system. Distinguish between a system with components in parallel and in series.
4) A remote control unit has 25 components in series. Each component has a reliability of 0.999. What is the reliability of the remote control unit. If it is desired to have a reliability of 0.996 for 3000 hours of operation, what should be the failure rate of each component? Assume that the time to failure for each component is exponentially distributed.

## 9.10 BIBLIOGRAPHY AND SUGGESTED READINGS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