Chapter 1

Introduction

1.1. Background

Reliability is one of the important parameters of the modern engineering systems. Practicing engineers and researchers have found a number of methods to increase system and component reliabilities. Increasing the safety margin, reinforcing redundancy, controlling the operating environment, employing more reliable components, and implementing a well designed maintenance policy are some of the important methods available for increasing the systems reliability. Depending upon the type of the system and its application, any combination of these methods can be implemented for achieving the desired reliability. For productive systems, once they were installed, implementation of these methods except maintenance, are heavily constrained because of time, space restrictions, and economy. Therefore, the industrial organizations are forced to get the most out of the equipments they already own through the implementation of more effective maintenance policies.

Productivity is a key strategy for manufacturing companies to stay competitive in a continuously growing global market. For achieving higher productivity, Industrial plants, machinery and equipment are becoming technologically more advanced and sophisticated. These systems integrate mechanical elements, electrical circuits, electronic devices, computers and software programs as subsystems and components. Recent developments such as automated manufacturing systems (AMS), lean and agile manufacturing, just in time (JIT) management systems, etc., have significantly improved the productivity. These increased sophistications result in:

- Increased investment – implementing new technologies, and installing new equipments require disposing the existing equipments and purchasing the latest ones, hiring and training the personnel on these new process, among other resources. All these require huge investment especially in manufacturing plants (Collins and Hull, 1986).
- Increased failure rate – as increasing the sophistications the system encapsulate more number of subsystems and components as its members. Under the integrated environment failure of any one subsystem or component leads to the failure of the entire system. Therefore, frequent break down of the system (Luce, 1999, Vineyard et al., 2000, and Holmberg, 2001).
- Increased mean downtime (MDT) – as systems complexities and automation increase it is difficult, and requires more time and effort for identifying, isolating and rectifying the faults. Therefore, the average downtime at failure increases with increasing the system complexities (Robinson, 1987, and Paz and Leigh, 1994).

The increased investments on production systems made the down times more costly and the frequent failures and increased MDT reduce the availability. These effects enhance the down time costs and should be minimized in order to improve the ROI. Designing and implementing an appropriate maintenance policy plays a crucial role in reducing the down time and improving the availability.

Further, as a result of increased sophistications, companies want to increase the number of repairmen and repair crews. Therefore, the percentage of employees working in the maintenance area has grown up. Finally, the fraction of maintenance expenditure of the total operational costs has increased. In modern industries, the maintenance expenses vary depending upon the type of industry; typically, figures such as 15 – 40% of production costs may be encountered (Al-Najjar, 2003). Furthermore, next to energy costs, maintenance spending can be the largest part of the operational budget (Dekker, 1996). If we contribute for any savings in maintenance expenses that directly improves the ROI and profitability of the organizations. Well designed maintenance policy does the same, which is the objective of the present research.

Well-maintained equipments and plants will only meet the market requirements of low-cost, high quality, and quick delivery (Stephen, 2000, Swanson, 2001 and 2003). Further, the importance of maintenance has been improving continuously since 1940 – 50, when the maintenance turns its view from reactive to proactive and predictive. Now it becomes an essential function to the modern organizations. The identification and implementation of the proper maintenance policy will enable organizations to avoid premature replacement costs, maintain stable production capabilities and control the deterioration of the system and its component parts (Vineyard et al., 2000).

1.2. Deterioration

Material properties may degrade due to factors involving the chemistry and structure of the bulk as well as the physics of surfaces, including interfaces in contact at the operating conditions. Change in mechanical properties, variations in surface characteristics, resistivity and surface energy, rubber hardening or softening with time, are typical examples of material degradation. On the other hand, component degradation (hard ware changes) may be ascribed to the process and to the very function the component is performing. Wear, dimensional changes with time, effect of contamination, and deleterious environmental factors, e.g. temperature, voltage, and radiation are relevant examples and sources of component degradation. Both the material and the component degradations lead to system deterioration.

During the life time of a system its condition (relative to its performance in required/specified functions) varies from an acceptable good state to an unacceptable bad/failed state. For many systems this transition is gradual over the life of the system/component. In this thesis the term deterioration is used to represent the process of transformation of a given system/component from the good operating state (brand new condition) to bad failed state. The failed state is either a real failed state or it is the state of the system at which its performance is no longer acceptable.

Existing literature on condition based maintenance shows that there exist certain measurable parameters of the system whose values directly depend on the deterioration condition of the system. The parameters such as temperatures, vibrations, pressures, crack lengths, metal particles present in the lubricant oil, etc, are available to predict the condition of the system. Further, the relationship between these parameters and the deterioration condition of the system can be expressed as given below.

$$D(t) = f(X_1(t), X_2(t), ..., X_n(t)) \tag{1.1}$$

Where D(t) is the deterioration level of a system/subsystem at time't', and X(t) is a condition information vector at time 't' such as a crack size, temperature, vibration, etc.

Random failure probability of many real life systems depend on the deterioration level (Barata et al., 2001). As increasing the deterioration level its failure probability also increase. A typical plot of the relationship between deterioration level and corresponding failure rate of the system is shown in Figure 1.1 (Barata et al., 2001 and 2002).

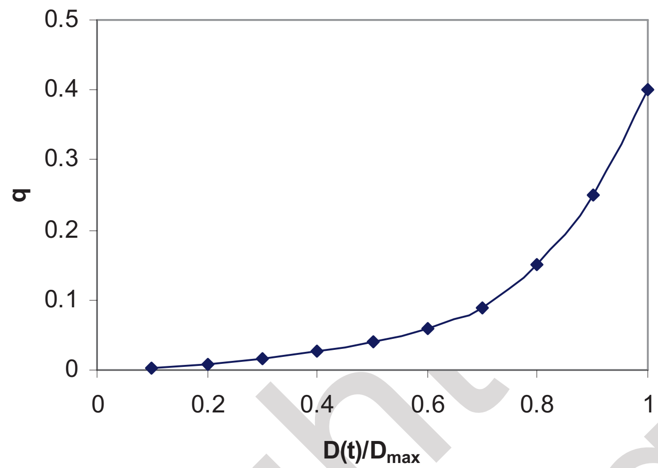

Fig. 1.1: System failure probability 'q' as a function of the degradation level (normalized to its maximum value; q(0)=0, q(D_{max})=0.4).

1.3. Maintainability and Maintenance

Maintainability is the probability that a given active maintenance action for an item under given conditions of use can be carried out within a stated time interval, when the maintenance is performed under stated conditions and using stated procedures and resources. Maintainability engineering tries to increase the efficiency and safety and to reduce the cost of equipment maintenance. Two important measures of maintainability are the mean time between failures (MTBF) and the mean time to repair (MTTR). The MTBF depends on the type of maintenance strategy applied and its designed reliability. On the other hand the MTTR depends on design of the product, skills of the repair crew, crew allocation policies; spare parts provision policies, etc.

Maintenance can be defined as the combination of all technical and associated administrative actions intended to retain an item or system in, or restore it to, a state in which it can perform its required function (Wang 2002).

The term maintenance includes various actions and tasks that are intended to increase or to retain the system reliability. Maintenance improves the reliability by extending equipment lifetime or at least the mean time to the next failure whose failure and repair may be costly. Furthermore, it is expected that effective maintenance policies can reduce the frequency of service interruptions and the many undesirable consequences of such interruptions (Endrayni et al., 2001).

The existing maintenance policies can be broadly classified based upon the state at which the specified maintenance activities are performed, as reactive or corrective maintenance (CM) and proactive maintenance. Traditionally organizations follow reactive maintenance strategy. According to this strategy maintenance activities are performed only when the equipments stopped working. CM may be applied to stand alone, non-critical assets, after cost-effectiveness review and justification. It is also applicable to assets which are no longer in production and where the cost of spares and service would be prohibitive. Later, the development of maintenance technology and the availability of trained maintenance personnel have led some companies to replace this type of reactive approach. A proactive maintenance strategy utilizes preventive and predictive maintenance activities to prevent equipment failures from occurring. In preventive maintenance, the system undergoes selected maintenance activities periodically or at prescheduled intervals. The application of this type of maintenance can reduce unexpected failures but can be expensive as it is often carried out without regard to equipment condition. Contrary to PM, in predictive or condition based maintenance (CBM), the system under consideration undergoes periodic or sequential inspections for knowing the condition of the system. The maintenance actions performed is based upon the observed condition at an inspection.

For the past four decades, many scholars and practitioners have shown interest in the study and development of maintenance models for systems with stochastic deterioration. One major reason for this is that maintenance models can be applied to a variety of areas such as military, industry, health, and the environment. As mentioned previously, as the systems become more complicated we require new technologies and methodologies, more sophisticated maintenance models and control policies to solve the maintenance problems.

1.4. Availability

The term availability is used to indicate the probability of a system or an equipment being in operating condition at any time t, given that it was in operating condition at t = 0 (Barlow and Proschan, 1975). In order to be in operating condition at time t, the system must not have failed or, if it had failed during the period t, it must have been repaired. Thus, availability includes both the aspects of reliability and maintainability.

Availability can be defined in several ways as indicated in the following Figure 1.2 (Barlow and Proschan, 1975, Lie, et. al., 1977, and Rao, 1992).

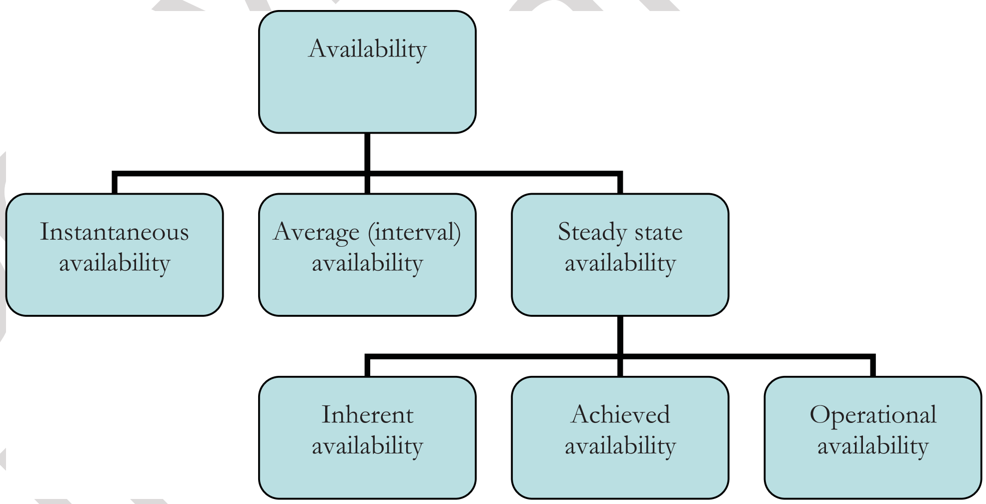

Fig. 1.2: Classification of availability definitions

1.4.1. Instantaneous Availability

It is the probability that the system is operational at any arbitrary time t. it is expressed as follows:

$$A(t) = P[X(t) = 1] \tag{1.2}$$

X(t) is an indicator variable defined as follows:

$$X(t) = \begin{cases} 1, & \text{if the system is up at time t} \\ 0, & \text{otherwise} \end{cases}$$

1.4.2. Average availability (or interval availability)

It is defined as the proportion of time during which the system is available for use in a specified interval (0, T):

$$A(T) = \frac{1}{T}\int_0^T A(t)dt \tag{1.3}$$

1.4.3. Steady state availability

This quantity is the probability that the system will be available after it has been run for a long time, and is a very significant measure of performance of a repairable system:

$$A(\infty) = \lim_{T \to \infty} A(T) = \lim_{T \to \infty} \frac{1}{T}\int_0^T A(t)dt \tag{1.4}$$

There are several different forms of the steady-state availability depending on the definitions of uptime and downtime. Inherent availability (A_i), Achieved availability (A_a), and Operational availability (A_o) are some important definitions which are discussed in the following sections. Depending upon the importance of downtime we can choose any one of these as steady state availability. In this thesis we consider steady state availability as one of the decision making parameter, which can represent any one of the above.

1.4.3.1. Inherent availability

It is defined as the proportion of time during which the system is operational, by considering only corrective maintenance down time and excluding ready time, preventive maintenance downtime, logistics (supply) time and waiting downtime:

$$A_i = \frac{MTBF}{MTBF + MTTR} \tag{1.5}$$

Where MTBF = mean time between failures and MTTR = mean time to repair.

1.4.3.2. Achieved availability

It is defined as the proportion of time during which the system is operational by considering both corrective and preventive maintenance downtimes and excluding ready time, logistics time, and waiting downtime.

$$A_a = \frac{MTBM}{MTBM + \overline{M}} \tag{1.6}$$

Where MTBM = mean time between maintenances and $\overline{M}$ = mean maintenance down time due to breakdown and preventive maintenance actions.

1.4.3.3. Operational availability

It is defined as the proportion of time during which the system is operational, by considering ready time, logistics time, and waiting time along with corrective and preventive maintenance downtimes

$$A_o = \frac{MTBF + readytime}{MTBF + readytime + MDT} \tag{1.7}$$

Where ready time = (operational cycle – MTBF – MDT), and MDT = mean downtime = $\overline{M}$ + delay time due to supply and administrative factors.