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RELIABILITY, AVAILABILITY AND MAINTAINABILITY ANALYSIS OF A PROCESS INDUSTRY: A STATE OF ART REVIEW

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ABSTRACT

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. The manufacture of highly complex 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 entire equipments. The importance of reliable operation has been realized in large complex process industries such as chemical, sugar, textile, paper plants and fertilizer plants etc. In these process plants to achieve the high availability and productivity, it is necessary that all systems/subsystems remain in upstate for a longer duration of time. However, these systems/subsystems are subjected to random failures due to poor design, lack of operative skills and wrong manufacturing techniques etc. causing heavy production losses. The plant working conditions and the repair strategies play an important role in maintaining the operating systems, operative for maximum duration i.e. optimal system availability. This can be accomplished only through performance evaluation and analysis of all the operating systems of the plant.

Keywords: Reliability; Availability; System-Sub System

1. INTRODUCTION

With the emerging demand of automation in the various industrial segments, the high capital investment is required for installing the production plants especially process plants like chemical, sugar, beverage, thermal, paper and fertilizer etc. It is essential to have high productivity and maximum profit from process plants for their survival. To achieve this end, availability and reliability of equipment in process must be maintained at the highest order. Unfortunately, this is not the case because failure is inevitable even though it can be minimized by proper maintenance, inspection, proper training to the operators, motivation and by inculcating positive attitude in the workmen. The performance of any system also affects its design quality and the optimization tools used. Thus the performance of a system may be enhanced by proper design, optimization at the design stage and by maintaining the same during its service life. The authors have discussed the performance analysis of the furnace draft air cycle in a thermal power plant. They have divided this particular system into three main subsystems. These subsystems are arranged in series and parallel configurations. For the analysis of availability, formulation of the problem has been carried out using Markov birth-death process based upon probabilistic approach. Failure and repair rates for all the subsystems are considered to be constant. A transition diagram representing inter relationship among the full working, reduced capacity and failed states has been developed. The effect of failure and repair parameters of each subsystem on the system availability has been determined [1]. Work is being done to develop a simulation model for the performance evaluation of feed water system of a thermal power plant using Markov Birth-Death process and probabilistic approach [2].Typical application areas include production plants especially process plants like chemical, sugar, beverage, thermal, paper, nuclear and fertilizer [3,4,5,6,7]. In this paper the authors have assessed the availability of crank-case manufacturing system in an automobile industry. The problem is formulated using probability consideration and supplementary variable technique. The system of equations governing the working of system consists of ordinary as well as partial differential equations. Lagrange method and Runge–Kutta method is used to solve partial differential equation and ordinary differential equation respectively [8]. Redundancy or standby is a technique that has been widely applied to improving system reliability and availability in system design. In most cases, components in standby system are assumed to be statistically identical and independent. However, in many practical applications, not all components in standby can be treated as identical because they have different failure and repair rates. In this paper, one kind of such systems with two categories of components is studied, which is named k-out-of-(MCN): G warm standby system. In the system, one category of the components is of type 1 and the other type 2. There are M type 1 components and N type 2 components. Components of type 1 have a lower failure rate and are preferably repaired if there is one failed. There are r repair facilities available. By using Markov model, the system state transition process can be clearly illustrated, and furthermore, the solutions of system availability and reliability are obtained based on this. An example representing a power-generator and transmission system is given to illustrate the solutions of the system availability and reliability [9-12]. In order to improve system reliability, designers may introduce in a system different technologies in parallel. When each technology is composed of components in series, the configuration belongs to the series–parallel systems. This type of system has not been studied as much as the parallel–series architecture. There exist no methods dedicated to the reliability allocation in series–parallel systems with different technologies. We propose in these paper theoretical and practical results for the allocation problem in a series–parallel system. Two resolution approaches are developed. Firstly, a one stage problem is studied and the results are exploited for the multi-stages problem. A theoretical condition for obtaining the optimal allocation is developed. Since this condition is too restrictive, we secondly propose an alternative approach based on an approximated function and the results of the one-stage study [13-18]. Gupta S., Tewari P.C. and Sharma A.K. have assessed the reliability of feed water unit of a steam thermal power plant using probability theory and Markov Birth-Death process. They divided the feed water unit into three subsystems namely Boiler, Condenser and Feed water pump. After developing Transition diagram, the differential equations have been generated. These equations are then solved to determine the steady state availability of the system. Besides, Reliability prediction module for thermal power plant has been developed to predict operational availability of the system. The failure and repair rates of the different subsystems are used as standard input information to the module and decision matrices (availability values) are prepared accordingly by putting these failures and repair rates values in expression for availability. These decision models are developed under the real decision making environment i.e. decision making under risk and used to implement the proper maintenance decisions for the Feed Water Unit [31-32]. Herder P.M., Luijk J.A. and Bruijnooge J. have developed a RAM (Reliability, Availability and Maintenance) model, based on a Reliability Block Diagram (RBD) with a Monte Carlo simulation engine, for the GE industrial plastics Lexan plant (Resin section) in Bergen op Zoom, The Netherlands. The authors have also validated the model against actual historic plant data from two different sources (EMPAC - Enterprise Maintenance Planning and Control and DAS - Dent Administration System). The model was expected to increase the efficiency and effectiveness of preventive/corrective maintenance actions and accordingly result in higher plant reliability and less unexpected output shortfalls. The model was used to assess decisions concerning operation and shutdown policies of the plant and the results showed that the operation and maintenance could be further improved and thus the annual production loss could be further reduced [33]. Juang Y.S., Lin S.S. and Kao H.P. have proposed a genetic algorithm based optimization model to improve the design efficiency. They utilized object-oriented program technique to develop a knowledge system for the availability design of series-parallel systems, which enabled the users to retrieve, modify and fine-tune similar designs from the system database. The objective was to determine the most economical policy of components' mean-time-between-failure (MTBF) and mean time-to-repair (MTTR).They also developed a knowledge-based interactive decision support system to assist the designers set up and to store component parameters during the intact design process of repairable series-parallel system [34].Guo H. and Yang X. felt that Markov Analysis (MA) is a powerful and flexible technique to assess the reliability of Safety Instrumented Systems (SIS), but it is very fallible and time consuming to create models manually as the size of Markov models of SIS increases explosively with system becoming more complex. Hence, in this paper they presented a new technique to automatically create Markov models for the reliability assessment of SIS. According to them, compared with manual modeling, automatic Markov modeling is more effective, accurate and convenient and with a Markov model solving engine, more accurate reliability measures can be achieved because it covers most aspects that affect reliability, shows more flexibility and describes dynamic transitions among different states [35]. Gupta S., Tewari P.C. and Sharma A.K. assessed the reliability of ash handling unit of a steam thermal power plant using probability theory and Markov Birth-Death process. They divided the ash handling unit into four subsystems namely Electrostatic Precipitator (E.S.P), Hopper, Slurry pump and Lower pressure pump. After developing Transition diagram, the differential equations have been generated. These equations are then solved to determine the steady state availability of the system. Besides, Reliability prediction module for thermal power plant has been developed to predict operational availability of the system. The failure and repair rates of the different subsystems are used as standard input information to the module and decision matrices (availability values) are prepared accordingly by putting these failures and repair rates values in expression for availability. These decision models are developed under the real decision making environment i.e. decision making under risk and used to implement the proper maintenance decisions for the ash handling unit [36]. Kiureghian A.D. and Song J.described a decomposition approach together with a Linear Programming (LP) formulation which allows determination of bounds on the reliability of complex systems with manageable computational effort as, according to the authors, the computation of system reliability of complex systems e.g. water-, sewage-, gas- and power- distribution systems, is a challenging task. The approach is applicable to both, Multi state as well as two state systems. The approach has been applied to calculate the reliability of power network consisting of 4 substations and 69 components. They have also described a method for computing bounds on conditional probabilities by LP. Conditional probabilities are used for system reliability updating and for post-event planning and decision-making. The system reliability updating method is demonstrated by computing the conditional failure probabilities of the components in a substation [37]. Proper maintenance planning plays a prominent role in reducing production costs. Increasing availability of manufacturing systems and improving the quality also help a lot in the productivity enhancement. To improve the quality and quantity of a manufacturing related curriculum, there is need to emphasize more on operational management. Most common deficiency of our technological capability has been our failure to devote enough attention to the process technology. In manufacturing operation the inputs are: raw materials, energy, labour, machines facilities, information and technology etc. To achieve quality and quantity, efficient plant management is required to control the conversion process and the variables which affect the performance. The success of a plant depends on its excellent performance which is directly related to the qualitative and quantitative production. The analysis may forecast the future profit of a plant if the performances of three main systems, viz. financial, operational and management systems, are known.

2. RELIABILITY, AVAILABILITY AND MAINTAINABILITY CONCEPTS

2.1. Reliability

Reliability is concerned with the probability and frequency of failures (or more correctly, the lack of failures). A commonly used measure of reliability for repairable systems is the Mean Time Between Failures (MTBF). The equivalent measure for non repairable items is Mean Time To Failure (MTTF). Reliability is more accurately expressed as a probability of success over a given duration of time. It is an important factor in equipment maintenance because lower equipment reliability means higher maintenance. Barabady J. and Kumar. U. have conducted the reliability analysis of mining equipment at a crushing plant at Jajaram Bauxite Mine in Iran by dividing the crushing plant into six subsystems and found out the criticality of different subsystems from reliability and availability point of view. The researchers have emphasized that the reliability analysis is very useful for deciding maintenance intervals [30]. The basic requirement of a high plant performance is its equipment reliability because factors such as product quality, profitability and production capacity hinge on this crucial factor (reliability) alone. The reliability of a component for a period t is calculated as:

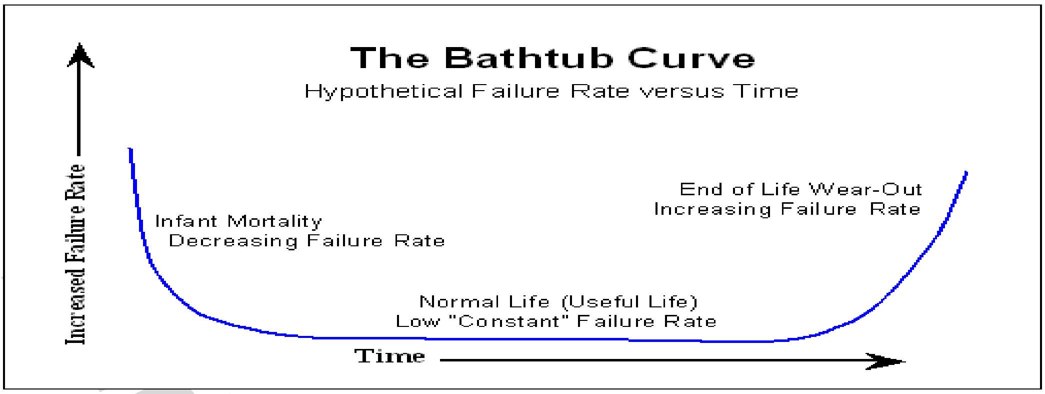

Figure 2.1. Bath - Tub Curve

In reliability analysis of an engineering system, it is often assumed that the hazard or time dependent failure rate of items follows the shape of a bathtub as shown in Figure 2.1. The bathtub curve has three distinct regions: infant mortality, useful life period and wear out period. The infant mortality is also known as burn in period or debugging period. During this period the failure rate decreases and the failures occur due to design and manufacturing defects, cracks, incorrect installation or setup, mishandling, defective parts, contamination and poor workmanship etc. The burn in period failures can effectively be reduced by burn in testing, acceptance sampling and quality control techniques. In the useful life period, the failure rate is constant and the failures occur randomly or unpredictably. Some of the causes of failures in this region include insufficient design margins, incorrect use, undetectable defects, human errors and unavoidable failures i.e. ones that cannot be avoided by even the most effective preventive maintenance practices. The useful life period failures can be reduced by incorporating redundancy in the system. The wear out period begins when the item passes its useful life period. During the wear out period the hazard rate increases. Some causes for the occurrence of wear out region failures are aging, inadequate or improper preventive maintenance, limited life components, friction, misalignments, corrosion, creep and incorrect overhaul practices. Wear out period failures can be reduced significantly by executing effective replacement and preventive maintenance policies and procedures.

2.2. Maintainability

Maintainability is defined as the measure of the ability of an item to be restored or retained in a specified condition. Maintenance should be performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair. Simply stated, aintainability is a measure of how effectively and economically failures can be prevented through preventive maintenance and how quickly system operation following a failure can be restored through corrective maintenance. Commonly used measures of maintainability in terms of corrective maintenance are the Mean Time To Repair (MTTR) and a limit for the maximum repair time. Maintainability is a design parameter, while maintenance consists of actions to repair or prevent a failure event. A model to find the optimal periodic inspection interval on a finite time horizon for a complex repairable system. In general, it may be assumed that components of the system are subject to soft or hard failures, with minimal repairs. Hard failures are either self-announcing or the system stops when they take place and they are fixed instantaneously. One version of the model takes into account the elapsed times from soft failures to their detection. The other version of the model considers a threshold for the total number of soft failures. A combined model is also proposed to incorporate both threshold and elapsed times. A recursive procedure is developed to calculate probabilities of failures in every interval, and expected downtimes. Numerical examples of calculation of optimal inspection frequencies are given. The data used in the examples are adapted from a hospital's maintenance data for a general infusion pump [19-25]. various studies on regular maintenance, also known as preventive maintenance, have been conducted and documented in the literature. some of the recent works are briefly reviewed as follows: smith and dekker study preventive maintenance in a 1 out of *n* system. They present a model using age-replacement where a machine is taken out for preventive maintenance and replaced by a standby one if its age reaches a certain value [26]. The nature of a repairable system can be described in terms of reliability, availability and maintainability. These matrices may be evaluated at different points of time in the working life of a system to observe its evolution. The matrices are often measured in the context of the actual maintenance action undertaken, whether preventive, condition based, emergency repairs conducted after failures, or those carried out in conformity with prescribed rules and regulations. The goal of all maintenance activities is to ensure operation of the system at reasonable cost over the useful life of the system. Conventional models for the system of reliability, availability and maintainability of repairable units tend to be either very simple or too cumbersome and intractable. Models based upon newer techniques like Simulation and Petri nets are finding increasing application in recent years. Maintainability is affected by several design features such as complexity of equipment, interchangeability and accessibility of components etc. Other factors affecting maintainability include those related to the environment and operation such as experience, training, skill and supervision of maintenance and operating personnel, availability of publications, procedural details for failure diagnosis, testing and calibration etc. Some of the above factors are intangible and there are few techniques available to measure them in specific numerical terms. It is often impossible to assess their individual effect on maintainability with any degree of confidence.

2.3. Availability

Availability is the probability that a system or component is performing its required function at a given point in time or over a stated period of time when operated and maintained in a prescribed manner. Availability may be interpreted as a probability that a system is operational at a given point in time or as the percentage of time, over some intersectional in which the system is operational. Availability depends on both reliability and maintainability. To predict system availability both the failure and repair probability distribution must be consider. Availability is always associated with the concept of maintainability. The maintainability function M (t) is defined as the probability that the equipment will be restored to operational effectiveness with in a specified time when the repair is performed in accordance with the prescribed conditions. It is clearly a function of time. Availability therefore depends upon both failure and repair rates. In general, the availability of a system is a complex function of reliability and maintainability.

This can be expressed as $A = f(R, M)$ (1.1)

Where A = system availability R = system reliability M = system maintainability

Fig 2.2 shows the availability response surface with reliability and maintainability as input. The equation (1.1) can be viewed as an input and output relation, where R, and M, are the inputs and A, is the output. The figure shows the availability response surface with R and M as inputs. The availability surface is a convex surface from the lowest portion to the highest level of availability.

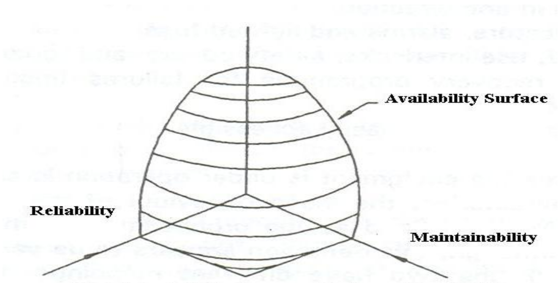

Fig 2.2 Availablity Response Surface with reliability and maintainability as inputs

Initially the availability improves rapidly with increase in reliability and maintainability. As these two inputs gradually increase, the rate at which availability increases is slower.

3. RELIABILITY AND MAINTENANCE EVOLUTION

The demand of modern technology used in the war, realized the importance and need for reliability. It was reported that during World War II nearly 60 percent of the airborne equipments shipped were damaged on arrival and 50 percent of the spare parts and equipments in storage became unserviceable before they were used. According to a report in 1949, about 70 percent of the electronic equipments possessed by the US Navy were not operating properly. In view of these difficulties Reliability Engineering emerged as a separate discipline in USA in the early 1950s. In December 1950, the US Air Force formed an adhoc group on Reliability of Electronic Equipment, to study the situation and recommend measures that would increase the reliability of equipment and reduce the maintenance work. In late 1952, the US department of Defence and electronics industry, jointly established an Advisory Group on Reliability of Electronic Equipment (AGREE). This group published its first report on reliability in 1957 recommending standard testing procedures for the new equipments to know the weak areas in design before production commencement. The approach to maintenance has changed dramatically over the last century. Up to about 1940, maintenance costs were considered as unavoidable costs and the only maintenance method used was corrective maintenance. Whenever an equipment failure occurred, a specialized maintenance workforce was called on to return the system to operation. Maintenance was neither incorporated into the design of the system, nor was the impact of maintenance on system and business performance duly recognized. The evolution of Operations Research (OR) from its origin and applications during the Second World War to its subsequent implementation in industry led to the widespread use of Preventive Maintenance (PM). Since the 1950s, OR models for maintenance have appeared at an ever increasing pace. These models deal with the effect of different maintenance policies and optimal selection of the parameters for the policies. In the 1970s, a more integrated approach to maintenance evolved in both the Government and Private sectors. New costly defence acquisitions by the US Government required a life cycle costing approach, with maintenance cost being a significant component. The close linkage between Reliability (R) and aintainability (M) was recognized. Consequently, ``R and M'' became more widely used term in defence-related systems. This concept was also adopted by manufacturers and operators of civilian aircraft through the methodology of Reliability Centered Maintenance (RCM) in the USA. In the RCM approach, maintenance is carried out at the component level and the maintenance effort for a component is a function of the reliability of the component and the consequence of its failure under normal operation. The approach uses failure mode effect analysis and to a large extent is qualitative. At the same time, the Japanese evolved the concept of total productive maintenance in the context of manufacturing. Here, maintenance is viewed in terms of its impact on the manufacturing through its effect on equipment availability, production rate and output quality.

4. MAINTENANCE IN PROCESS INDUSTRIES

Now a days in the process industries (due to automation), maintenance is considered as an integral part of the production process. It is done by optimal utilization of maintenance resources and by acquiring high availability level. For increasing (maximizing) the productivity, availability and reliability of equipment/subsystems in operation must be maintained at highest order. To achieve high production goals, the systems should remain operative (run failure free) for maximum possible duration. But practically these systems are subjected to random failures owing to poor design, wrong manufacturing techniques, lack of operative skills, poor maintenance, overload, delay in starting maintenance and human error etc. These causes lead to non-availability of an industrial system resulting into improper utilization of resources (man, machine, material, money and time). So, to achieve high production and good quality, there should be highest system availability (long run system availability). Generally, the process industries comprise of large complex engineering systems or subsystems arranged in series, parallel or hybrid configurations. For efficient operation of a process plant, each system should run failure free for a long period of time. A suitable maintenance system must be designed and developed to suit the requirements of a process industry where raw material is processed from input to finished products. Therefore, a detailed system behavioural analysis and a scientific maintenance planning will help a lot in this direction.

5. CONCLUSION

Frequent advancement in the technology and automation in manufacturing sector has increased the complexity of equipment beyond bounds and hence their reliability poses a thrusting question especially for the mass production and process industries. Most of the firms adopting 'process' oriented manufacturing such as chemical, fertilizer, sugar, paper, oil refinery and textile etc. comprise of large complex engineering systems/subsystems which are arranged in series, parallel or a combination of both. Hence, it becomes imperative to have reliable systems for efficiency, long term survival and growth. Thus, all the workable engineering systems are expected to remain operative with the maximum efficiency for the maximum duration to ensure their reliable operation.

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