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Review Article

RAM ANALYSIS OF SOME PROCESS INDUSTRIES: A CRITICAL LITERATURE REVIEW

Pardeepkumar[1]*, Rahul Kumar[2], Parth Dahmani[2] and Deepak Narula[2]

*Corresponding Author: Pardeepkumar, ✉ pardeepkamboj@yahoo.com

In today's world of the automation, it is impossible to survive without reliable systems. Thus, all the working engineering systems are expected to remain operative with the maximum efficiency for the maximum duration, i.e., reliable operation. 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. These failed systems can be brought back to their operating states after repair or replacement in minimum possible down time. 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. The system performance can be quantified in terms of the availability if the operating system is modelled mathematically and analysed in real working conditions. It can be further optimized by means of some advanced optimization techniques.

Keywords: Modeling, Reliability, Steady state availability, Maintainability, Performance evaluation

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, 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

[1] Department of Mechanical Engineering, N.I.T. Kurukshetra, Haryana, India.

[2] Department of Mechanical Engineering, ACE Ambala, Haryana, India

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. 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.

In process industries too, such as Chemical, Paper, Sugar, Brewery, Cement, Food processing, Thermal power plants and Fertilizer plants to achieve the goal of high system availability and to utilize maximum plant capacity, it is necessary that its various subsystems should remain in upstate for a longer period. However, these systems or subsystems are subjected to random failures. Depending upon the nature and extent of failure, it may result into reduced or zero production. No doubt that failed systems can be brought back to their operating state after repairs or replacements of some of the components. But, in this case the factory operating conditions and also the repair policies adopted in the organization play an important role in maintaining the system operative with full capacity for maximum duration. Designing such a process, from the view point of high system availability, would necessitate a prior knowledge of the system behavior, available repair facilities, etc. Analysis and modeling of such systems may prove beneficial in evaluating the performance of subsystems and the degree of interaction between the constituent subsystems. This would also yield a framework for system design based on availability and optimum repair policy.

Reliability, Availability and Maintainability Concepts

Reliability: It is concerned with the probability and frequency of failures (or more correctly, the lack of failures). A commonly used measure of reliability forrepairable 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. The reliability of a component for a period t is calculated as: $R(t) = e^{-at}$ Where, a is the mean failure rate. t is Burn in period Useful life period Wear out period Time.

Maintainability: It is defined as the measure of the ability of an item to be restored or retained in a specified condition. Simply stated, maintainability 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.

Availability: In an industrial system, high plant availability plays an important role in the direction of industrial growth as the profit is directly related to the production volume which depends upon plant performance. To achieve high system availability, proper maintenance management system supported by adequate resources such as manpower, spares and machines, etc. are required. Mathematically, the term availability is used to indicate the probability of a system or equipment being in operating condition at any time *t*. The availability of a system is a combined measure of both reliability and maintainability.

RAM ANALYSIS: A CRITICAL REVIEW

Historical Background: Reliability engineering has been in existence as a distinct discipline for nearly the past five decades. Even now, one finds that the subject of repairable systems has not gained its due importance in reliability literature. A study of the development of this engineering discipline does helps to identify the reasons for this deficiency and also understand the difficulties involved in analysis of repairable systems as far as their reliability, availability and maintainability are concerned. Development of reliability has strong links with quality control and its development. In early 1920s, statistical methods were developed at Bell Telephone Laboratories, USA, to solve their quality control problems which provided them a basis for further developments in the area of statistical quality control. Subsequently, quality control techniques were popularized by American Standard Association and American Society for Mechanical Engineers along with Bell Laboratories. The mathematical theory of reliability took shape and grew as a result of the demands of developing technology and in particular out of the experiments with complex military systems during World War II (1939).

Ramin Process Industries

Terje Aven (1990) presented some simple approximation formulae for the availability of standby redundant systems comprising similar units that were preventively maintained. The formulae were established using standard Markov theory. A number of simulations had been performed in order to evaluate the formulae. The simulations showed that the formulae gave very good approximations for various preventive maintenance regimes.

Hassett (1995) combined time varying failure rates and Markov chain analysis to obtain hybrid reliability and availability analysis. However, combining these techniques can, depending on the size of the system, result in solutions of the Markov chain differential matrix equations that are intractable. The authors have identified solutions that are tractable. Tractable solutions were found for the l-component 2-state and the 2-component 4-state configurations. Time varying failure rates were characterized by a general polynomial expression. The general polynomial failure rate provides flexibility in modeling the time varying failure rates that occur in practice.

Kumar (1997) carried out stochastic analysis of the power generation and coal handling systems in a thermal power plant with Markov chains. They studied the performance of the system in three states viz. good, reduced and failed. Taking constant failure and repair rates for each working unit, the mathematical formulation was done using the Birth-Death process. Expressions for steady state availability and the Mean Time Between Failures (MTBF) were derived. The graphs were given, depicting the effect offailure and repair rates on the system availability.

Michelsen (1998) assessed the reliability analysis as a useful tool for risk analysis and the design of safety system. He proposed to encourage the use of reliability technology: i.e., to better cooperation with industry. He focused on specific problems as experienced by the industry rather than system modeling; development of simple methods to be applied by the people who own the problem. He used RAM analysis means reliability-availability-maintainability for screening purposes.

Elegbede (2003) proposed a GA-based approach to solve a multi-objective optimization problem and aimed at maximizing the availability and minimizing cost of repairable parallel-series systems. In the first step, they used the weighting technique to transform the problem into a problem of single-objective optimization. Next they relaxed the constraints by mean of the technique of exact penalty to reformulate the problem and to find a solution in the second step, they developed the GA for which they have tried to provide guidance to adjust the parameters and control the fitness. For that purpose, they designed an experiment plan that shows its relevance for the GA implementation.

Marzio Marseguerra (2004) proposed a multi-objective optimization approach, based on genetic algorithms, which transparently and explicitly account for the uncertainties in the parameters. The objectives considered (the inverse of the—expected system failure probability and the inverse of its variance), were such as to drive the genetic search toward solutions which were guaranteed to give optimal performance with high assurance. For validation purposes, a simple case study regarding the optimization of the layout of a pipeline was firstly presented. The procedure was then applied to a more complex system taken from literature, the Residual Heat Removal safety system of a Boiling Water Reactor, for determining the optimal STI of the system components. The approach provided the decision maker with a useful tool for determining those solutions which, besides being optimal with respect to the—expected safety behavior, allow a high degree of assurance in the actual system performance.

Trivedi (2005) presented the application of Markov Decision Process (MDP) algorithm in searching for the optimal maintenance policy for condition based maintenance, and they have also presented a joint optimization of inspection rate and its corresponding maintenance policy. Under a special case when the optimization objective is steady-state availability and the deterioration rate at each failure stage is the same, they found that the optimal policy is a threshold-type maintenance policy.

Rajpal (2006) observed that there are many factors that affect the Reliability, Availability and Maintainability (RAM) of a complex repairable system. These factors include machinery (type, number of machines, age, arrangement of machines relative to each other, arrangement of components in the machine, inherent defects in components), operating conditions (level of skill and number of operating personnel, working habits, inter personnel relationships, absenteeism, safety measures, environmental conditions, severity of task assigned, shock loading), maintenance conditions (competence and strength personnel, attendance, working habits, safety measures, inter-personnel relationships, defects introduced by previous maintenance actions, effectiveness of maintenance planning and control) and infra structural facilities.

Armen Kiureghian (2007) Closed-form expressions were derived for the steady-state availability, mean rate of failure, mean duration of downtime and lower bound reliability of a general system with randomly and independently failing repairable components. Component failures were assumed to be homogeneous Poisson events in time and repair durations were assumed to be exponentially distributed. The results were expressed in terms of the mean rates of failure and mean durations of repair of the individual components. These expressions provide a convenient framework for identifying important components within the system and for decision-making aimed at upgrading the system availability or reliability, or reducing the mean duration of system downtime.

Faisal Khan (2008) presented a risk-based methodology to estimate optimal inspection and maintenance intervals which maximize a system's availability. The methodology was comprised of two steps: availability modeling and risk-based inspection and maintenance calculations. The proposed methodology was applied to the steam generating system of an oil fired thermal power plant. The authors presented a case study. The case study involved the application of the method to a steam generating unit in a power generating plant. The unit under consideration was further subdivided into ten subsystems. These subsystems are simulated using the proposed approach to achieve a target availability of 99.9%.

Ying Shen Juang (2008) proposed a genetic algorithm based optimization model to improve the design efficiency. The objective was to determine the most economical policy of components' Mean-Time-Between-Failure (MTBF) and Mean Time-To-Repair (MTTR). He 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. He 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.

Sharma (2008) presented the application of RAM analysis in a process industry.Markovian approach is used to model the system behavior. For carrying out analysis, transition diagrams for various subsystems were drawn and differential equations associated with them were formulated. After obtaining the steady state solution the corresponding values of reliability and maintainability were estimated at different mission times. The computed results were presented to plant personnel for their active consideration. The results proved helpful to them for analyzing the system behavior and thereby to improve the system performance considerably by adopting and practicing suitable maintenance policies/strategies.

Sanjeev Kumar (2009) discussed the performance evaluation and availability analysis of ammonia synthesis unit of a fertilizer plant. The fertilizer plant is a complex and repairable engineering system comprises of various units viz. shell gasification and carbon recovery, desulphurization, co-shift conversion, decarbonation, nitrogen wash and ammonia synthesis, etc. One of the most important functionaries of a fertilizer plant is ammonia synthesis unit. This unit consists of five subunits arranged in series and parallel configurations. For the evaluation of performance and analysis of availability, a performance evaluating model had been developed with the help of mathematical formulation based on Markov Birth-Death process using probabilistic approach. The findings of this paper are therefore, considered to be useful for the analysis of availability and determination of the best possible maintenance strategies in a fertilizer plant concerned.

Gupta (2009) assessed the reliability and availability of a critical ash handling unit of a steam thermal power plant by making a performance analysis and modeling, using probability theory and the Markov Birth-Death process. After that, steady state probabilities were determined. Certain decision matrices were developed, which provide various availability levels. The behavior analysis of the reliability module revealed that the availability decreases with increasing failure rates, while operational availability improves with initial increases in repair rates for different subsystems.

Khanduja (2010) dealt with the mathematical modeling and performance optimization for the paper making system in a paper plant using genetic algorithm. The paper making system had been divided into four main subsystems, arranged in series and parallel. The mathematical formulation of the problem was done using probabilistic approach and differential equations are developed based on Markov birth-death process. These equations were then solved using normalizing conditions to determine the steady state availability of the paper making system.

Carazas (2011) presented a method for reliability and availability evaluation of Heat Recovery Steam Generator (HRSG) installed in combined cycle gas and steam turbine power plant. The method's first step consisted in the elaboration of the steam generator functional tree and development of failure mode and effects analysis. The next step involved a reliability and availability analysis based on the time to failure and time to repair data recorded during the steam generator operation. The third step, aiming at availability improvement, recommended the fault-tree analysis development to identify components the failure (or combination of failures) of which can cause the HRSG shutdown. The availability and reliability of the HRSGs presented in the study reflect on-site behavior, including the effects of changes in feed water systems maintenance policy.

Kumar (2011) discussed the mathematical modeling and performance optimization of CO_2 cooling system of a fertilizer plant using genetic algorithm. Differential equations had been derived based on Markov Birth-Death process using probabilistic approach. These equations were then solved using normalizing conditions to determine the steady state availability of the CO_2 cooling system.

Sinha (2011) stated that Brake-by-wire is one such system that interfaces with active safety features built into an automobile, and which in turn is expected to provide fail-operational capabilities. In this paper, building up on the basic concepts of fail-silent and fail-operational systems design, the author proposes a system-architecture for a brake-by-wire system with fail-operational capabilities.

Kajal (2012) dealt with the performance optimization for skim milk powder unit of a dairy plant at National Dairy Research Institute (NDRI), Karnal using Genetic Algorithm (GA). The failure and repair rates of the subsystems were taken from maintenance history sheets, which followed the exponential distribution. The mathematical formulation was carried out using probabilistic approach and the Markov birth – death process was used to develop the difference differential equations. The steady state availability expression had been derived using normalizing conditions. The optimal values of failure/repair rates of each subsystem of the skim milk powder unit had been evaluated using Matlab 7.1 GA tool. The steady state availability obtained from Markov analysis was also compared with the optimal availability calculated through GA tool. So, the findings of the paper will be highly useful to the plant management for developing proper maintenance strategies which can be implemented in order to enhance system performance.

RESULTS

It has been found that a lot of work has been done in the field of Reliability Engineering particularly in Thermal Power Plant, Paper Industry, Fertilizer Industry, Sugar Industry, Nuclear Power Plant and Oil Refinery etc. Some research work has also been carried out on availability analysis of various processes industries. But very limited work has been done in the field of reliability and availability analysis with variable failure and repair rates. A number of studies have been carried out to analyze the availability and reliability using different techniques. Some of the techniques used are:

- Failure Mode Effect and Analysis
- Markov Models
- Reliability Block Diagram method
- Multi-objective Optimization Approach based on Genetic Algorithm
- Fault Tree Analysis
- Petri Nets
- Artificial Neural Networks
- Extended Block Diagram method
- Monte Carlo Simulation Technique, etc.

But, still, there is great scope of future research in this field as limited studies regarding development of Decision Support System have been carried out in process industries. The identified gaps in the literature provide an opportunity of research in the field of reliability. There is vast scope of research in this area due to fact that it encompasses a wide range of activities in the following research areas:

- Reliability and Availability Modeling
- Maintenance Cost Optimization
- Maintenance Policy Selection

FUTURE SCOPE

We intend to further analyse the various methods and models so far proposed. So that we could suggest improvements in the existing models and also in the various methodologies used to assess reliability.

CONCLUSION

By going through the literature survey we have focused on the various views given by numerous researchers on reliability engineering. Analysis of the various factors on which the reliability of systems depends has been done. Some research work has also been carried out on availability analysis of various processes industries. But very limited work has been done in the field of reliability and availability analysis with variable failure and repair rates. The major finding of the study is that the models under review reflect either infinite or finite number of failures. All exponential distribution based models reflect finite failures and logarithmic distribution based model reflect infinite failures.

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