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A CRITICAL REVIEW OF RAM METHODOLOGY: ANALYSIS AND PERFORMANCE EVALUATION IN INDUSTRIAL COMPLEXITIES

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Abstract

This paper investigates the reliability, availability and maintainability (RAM) characteristics of a in different systems of the process industries. Critical mechanical subsystems with respect to failure frequency, reliability and maintainability are identified for taking necessary measures for enhancing availability of the respective industries. As complexity of the systems increasing across the various sectors so performance evaluation becomes necessary for the smooth functioning of all the systems of respective industry. The study explores the evolution of RAM approaches over time, highlighting their significance in ensuring the efficient operation of intricate systems. It provides an overview of the historical development and current state of RAM practices in the complex system of the industries. A comprehensive review of academic literature from the past two decades, including books, journals, and scholarly articles, is conducted to expand the analysis, mainly focus on the evaluating RAM methodology in diverse industrial contexts, different complex system and other process industries.

Keywords: Reliability, Availability, Maintainability, Performance Evaluation.

I. Introduction

Today, industries are increasingly focusing on the principles of Reliability, Availability, and Maintainability (RAM). Growing competition, tighter production schedules, budget constraints, and the constant demand for cheaper, higher-quality products have heightened the importance of utilizing RAM engineering tools. As industrial systems become more complex, reliability simulation has emerged as the most effective and preferred method for addressing modern real-world challenges—challenges that are often difficult or even impossible to solve using traditional analytical methods. This simulation-based approach is now widely adopted across various industries, with RAM analysis becoming the standard tool.

Reliability of a system is associated with the prediction and occurrence of failures (or more correctly, the lack of failures). The term MTBF (Mean Time between Failures) is generally used to measure the reliability of repairable systems and similarly MTTF (Mean Time to Failure) term is commonly used for non-repairable systems. Reliability is more accurately expressed as it is the probability of a machine that can perform its intended function successfully (i.e. without failure) over a given duration of time under specified conditions. The performance of the plant depends upon the reliability of different components and equipment used. Reliability is crucial factor because it affects such as product quality, production capacity and profitability.

Availability is a key parameter used to evaluate the performance of repairable systems, as it depends on both reliability and maintainability. It is defined as the probability that a system will be operational when needed. In other words, availability is the likelihood that a repairable system is functioning and not experiencing a failure or undergoing repairs at a specific time. This metric ranges from 0 to 1 and accounts for both failure and repair rates.

According to British Standards 4778, availability is the ability of a product, considering its reliability and maintainability, to perform its intended function over a specified time period and under defined environmental conditions. Put simply, it reflects the probability that a system is operational at a given moment—the period during which the equipment is actively functioning. Availability can be calculated by measuring the downtime of a machine or piece of equipment. However, for repairable systems, availability is typically analyzed by considering the failure and repair rates of its sub-systems. It's important to note that a system may be available but not necessarily reliable.

Maintainability, while related to both reliability and availability, has its own distinct meaning and significance. It is typically defined as the probability that a machine or its components can be repaired and restored to working condition within a specified time frame. Maintainability and availability are closely linked—availability decreases as repair time increases for a failed system. In other words, maintainability refers to how quickly a system can be restored to its original state after a failure. Also known as serviceability, maintainability involves various methods aimed at detecting problems early and minimizing system downtime. Ultimately, the combination of reliability and maintainability forms the basis for the concept of availability.

This paper provides a critical review of the literature on RAM (Reliability, Availability, and Maintainability) methodologies, focusing on improving system availability while reducing operational costs. Additionally, the paper explores how various optimization techniques, based on performance analysis and maintenance requirements can further enhance system performance. Modelling tools such as Monte Carlo simulations, Petri Nets, Weibull analysis, Pareto analysis, and Markov modeling are highlighted as valuable in selecting effective maintenance and replacement strategies.

II. Literature Review

The literature review comprehensively study of literature has led to a detailed investigation into the aspects of reliability, availability and maintainability. The literature review primarily covers the period from 2000 to 2023, providing a contemporary perspective on the field. Among the various tools and methodologies for modeling system performance, RAMS stands out as a comprehensive approach that addresses both the engineering and management aspects of a plant. RAMS is particularly valuable as it assesses system performance across the design and production phases, offering insights that span the entire lifecycle of the system.

Bansal et al. [1] purposed a study approach based on neural network for optimized the parameters and performance of the casting process. With the help of this technique, availability, reliability and profitability of the system has been analyzed which help to predict the critical component of the system so that an effective maintenance scheduled can be planned.

Kumar et al. [2] analyzed the availability of the system by dividing the thermal power plant into six distinct systems and found that availability is significantly low, with boiler tube failure identified as a major contributing factor. Then, with the help of implementing an effective maintenance schedule to reduce the failure rate which help to decrease the plant shutdown periods and enhance overall system availability.

Daya and Lazakis [3] investigated the specific challenges faced by operators related to environmental conditions, operational demands, and technological issues impacting availability, maintenance and reliability of the system. A framework was developed using outputs from DFTA minimal cut set analysis and RPN from FMECA, which served as inputs for a Bayesian Belief Network (BBN) to analyze the availability of a ship's marine diesel generator (DG) system. With the help of BBN influence diagram, a decision support system (DSS)has been developed for maintenance strategy selection. The overall outcome of the DSS indicated a relatively high level of system unavailability.

Singla et al. [4] examined the most critical subsystem by taking variable failure and repair rates from all different subsystems. It focuses on the sensitivity analysis of a complex repairable threshing machine, which consists of 21 subsystems arranged in a series configuration. The machine operates at full capacity when the threshing drum and feeding hopper are fully functional, while the concave subsystem and blower operate at reduced power.

Kumar et al. [5] examined the operational availability of the Veneer layup system at a plywood production facility using Petri Nets for modeling. The study examined how different subsystem failure and repair rates affect system availability, highlighting crucial subsystems that need special attention. The results help maintenance engineers develop efficient planning techniques.

Kumar et al. [6] analyzed the factors which are significant causes of poor availability in thermal power plant. The authors developed the mathematical equations which have been used to find out the availability and it was found that the value of availability is very low and boiler tube failure is one of the most critical factors for this low availability of system.

Berrouane et al. [7, 8] proposed the maintenance decisions support system for the Coal Ash Handling System of a subcritical Thermal Power Plant. By using state probabilities and normalization conditions, a model was developed and then performability matrices were created based on repair and failure rates for all the subsystems. On further analysis, it was observed that ESP as the most critical and ash silo as the least critical subsystem, which help to make a Decision support system.

Kumar et al. [9] analyzed the poor availability of a thermal power plant, which was divided into six systems, including a waste gas heating system. Boiler tube failure, especially in the economizer zone due to erosion from high-velocity flue gas, was identified as a key factor. Reducing erosion in economizer tubes through CFD analysis can minimize failures, shorten shutdown periods, and improve system availability.

Parkash & Tewari [10] reviewed the effectiveness of Reliability, Availability, Maintainability, and Safety (RAMS) approaches in different mechanical systems of process industries. It examines a wide range of research, including articles, conference papers, and books, that address RAMS applications in both industry and research. The review covers various tools, techniques, and methods useful for both qualitative and quantitative analysis, providing insights into the past and present state of RAMS practices.

Parkash & Tewari [11] focused on performance modeling and proposed a Decision Support System (DSS) in an assembly line for prioritizing maintenance system using a probabilistic approach. The system divided into various subsystems: Shot Peening, Painting Machine, Assembly Platform, and Riveting Machine. A Markovian approach was used to model performance, with steady-state probabilities calculated through a transition diagram and differential equations and decision matrices were created with different failure and repair rates.

Kumar et al. [12, 13] developed a maintenance decision support system for repairable equipment of a thermal power plant so that the availability and performance have been improved.

Lu et al. [14] suggested a method of quality improvement and preventative maintenance for a system. To give the financial gains, a machine reliability model that considers the effects of component deterioration states on quality is built based on the proportional hazard model.

Pan et al. [15] assessed the reliability of the Reactor Protection System (RPS) using the proposed method, which is then compared to models based on two other contrasting methods. This comparison confirms the effectiveness and accuracy of the proposed approach.

Kumar et al. [16] presented a decision support system for providing maintenance orders, critical for efficient operations. It also evaluates the performability of a coal handling system in a thermal power plant using stochastic Petri nets (SPN) and GRIF software. By varying failure and repair rates, performability metrics were used to predict subsystem maintenance priorities. The study analyzes how these variations affect system performance and availability.

Patel and Joshi [17] proposed a model for complex manufacturing systems with deadlock, followed by Petri Net analysis to generate the reachability tree. The aim is to determine the minimum number of pieces required to maintain a desired throughput level while ensuring sufficient time to meet batch size constraints.

Kołowrocki et al. [18] presented a simulation method based on Monte Carlo for evaluating the reliability of a multistate system under a variable operation process. By linking the system reliability model and operation process model, a general reliability model is proposed to assess the system's performance under changing conditions and determine its reliability characteristics.

Kumar [19] examined the impact of failure and repair data on the availability and reduced capacity of a liquid milk processing plant. Using the Petri Nets approach, the system is modeled by dividing it into four subsystems in series and findings are useful not only for plant owners but also for professionals in other fields who wish to analyze and predict equipment behavior.

Kajal et al. [20] suggested a decision support system based on their study of the butter oil unit of a dairy plant. The butter oil unit's mathematical model was designed by utilizing the Markov Birth-Death process. The unit's differential equations were derived via a probabilistic approach that utilized a transition diagram.

Sachdeva et al. [21] evaluated an enhanced maintenance planning approach to reduce operating and maintenance costs by modeling and examining the performance of a feeding system using Petri Nets (PN) and a Markovian method in the paper industry.

Gupta et al. [22] Utilized a Markovian method to develop a Decision Support System (DSS) after assessing the performance of the feedwater system in a thermal power plant. The maintenance department uses the DSS to determine optimal maintenance intervals.

Sania et al. [23] presented a model to assess system reliability, including availability, profit, and mean time to failure (MTTF), considering three stages of deterioration (minor, medium, major). Markov models were used, based on state transitions and differential equations, to evaluate availability, busy period, profit, and MTTF.

Aven [24] reviewed key concepts of risk analysis and management by addressing common myths, such as equating risk with expected value, uncertainty, or probabilities. It concludes that risk involves both consequences and uncertainties, extending beyond expected values and probabilities.

Shubinsky et al. [25] proposed a method of technical systems for calculating reliability and functional safety, which allows deriving exact formulas for stationary parameters directly from the system state graph. This method applied to both Markov and semi-Markov models and also included the examples of calculating safety, availability factors, and time parameters for a two-channel safety-related device.

Ramirez-Marquez et al. [26] examined a complex system called a multi-state series-parallel system (MSPS). This system consists of binary components with limited capacity, which is capable of delivering various degrees of performance for the overall system. They claim that the varying degrees of demand that need to be fulfilled throughout the system's operation make the system multi-state, and that the new solution technique provides several unique advantages.

Ebrahimi N.B. [27] outlined the aspects of Grid and Grid modeling, a distributed software-hardware environment with a new computation and job flow management structure. A general model scheme was developed to analyze user-resource interaction issues and formulated specific mathematical tasks and discussed methods for solving them.

Tang J. [28] developed a novel method for assessing mechanical system reliability was proposed, utilizing graph theory and Boolean functions. Graph theory was first applied to develop a reliability formula that accounts for the connections between subsystems and components. Then, the failure interactions between two specific system components were analyzed using Boolean functions.

Savsar, M. et al. [29] developed an appropriate mathematical model incorporating a versatile machine, a pallet handling system, and a loading/unloading robot. They made the assumption that the times of operation, loading/unloading, and material handling were random. Afterwards, the operation of a fully reliable and an unreliable flexible manufacturing cell (FMC) were analysed and compared.

Kumar et al. [30] suggested a maintenance plan for the proper working of a beer plant so that the availability can be improved. With the help of Markov, they found the performance and then improved the performance by reducing the failure rate with a well plan maintenance policy.

III. Research Gap

After thoroughly reviewing the literature, some concise observations regarding the use of RAM methodology in different complex system of the process industries:

- Most of Most research has focused on reliability in process industries like thermal power plants, ply-board processing unit, paper industries, sugar, fertilizer, dairy plants, and oil refineries, rather than in product-based industries.
- Many researchers have studied methods to improve plant availability through effective maintenance, but few have examined the link between availability and break-even analysis. It's important to note that higher plant availability directly reduces the time needed to reach the break-even point.
- The literature review reveals that several methods are used for both quantitative and qualitative plant analysis, including Reliability Block Diagrams (RBD), Fault Tree Analysis, Markov models, and Petri Nets. Each method has its pros and cons. For example, the Markov chain is a powerful tool for stochastic reliability and availability analysis, but it faces the challenge of state explosion, even in small systems. Petri Nets, which consist of Places, Transitions, Arcs, and Tokens, have gained attention due to their simplicity and balanced modeling and decision-making capabilities, though they tend to increase system complexity.
- Most studies have used steady-state availability to evaluate the performance of industrial systems through Markov modeling. However, only a few have tackled these mathematical models under more realistic industrial conditions.

IV. Conclusion and Future Scope

A critical review of the available literature highlights the effectiveness of various RAMS tools and techniques applied in different plants to reduce the cost of plant non-availability. Plants are typically divided into multiple systems or subsystems for effective maintenance planning, ensuring prolonged system availability. A decision support framework using statistical analysis has been developed, utilizing tools such as Reliability Hazard Analysis, FMEA, Reliability Block Diagrams, Fault Tree Analysis, Reliability Growth Analysis, Root Cause Analysis, Finite Element Analysis, Markov Analysis, and Petri Nets. Each of these techniques has distinct advantages and disadvantages, which are discussed in the paper.

Conventional modeling and optimization techniques may be insufficient for addressing issues in plants with continuous wear and tear, like those in product industries. Therefore, advanced methodologies such as Fuzzy Logic, Particle Swarm Optimization (PSO), Genetic Algorithms (GA), Artificial Neural Networks (ANN), and MATLAB software are being implemented to tackle these challenges more effectively.

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