Critical Review Of Rams Tools And Techinques For The Analysis Of Multi Component Complex Systems

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Abstract

This work provides the critical review of usefulness of Reliability, Availability, Maintainability and Safety (RAMS) approaches in complex mechanical systems. A broad range of research works available such as articles, conference proceedings and books covering RAMS approaches in industries as well as in the field of research is critically reviewed. These include different tools, techniques and methods which may be helpful in qualitative as well as in quantitative analysis. It provides the informations about the past and current scenario of RAMS practices in industries as well as in research. In this work the authors look for certain articles which included two or more aspects of RAMS. Limited work is reported in the field of safety.

Keywords- Reliability, Availability, Maintainability, Safety, Decision Support System, Markov, Petri Nets.

1. Introduction

Modern day industrial scenario has improved the process of designing and manufacturing of the systems which are more complex, high capacity and cost. It requires the high availability at reasonable cost. The consequences of low availability of these systems led to desire for high reliability and Maintainability (Saraswat et al., 2008). Reliability, Availability, Maintainability and Safety (RAMS) are four system dimensions that are of great interest to system developers, engineers, logisticians, and users. It affects the utility and life-cycle costs of system collectively. RAMS analysis has becomes a dynamic field of research to measure the performance of any operational system as per its required features. However the accuracy of analysis largely depends upon how the issues and challenges related to RAMS are addressed while planning the operational strategies which enhance the system performability (Hameeda et al., 2012).This paper critically reviews the literature on RAMS tools and techniques which increases the system availability and reduces the running cost. **Reliability** may be defined as the probability of success of a system that will perform its intended function adequately for a specified period of time (ASQ, 2011).**Maintainability** is the ability of a system to restored its functional state using prescribed maintenance procedures (BS4778, 1991).**Availability** generally known as operational reliability, is the ability of an system to perform its adequate function over a stated period of time in the given environment (BS4778, 1991).

Plant availability is mainly depends upon the reliability and maintainability of the system during design as well as operational stage i.e. A= f(R, M). **Safety** is a dimension which is essential for product cycle. It may be defined as the state of being free from any harm or danger. Principles of safety management can be suitably applied to various industries such as automotive, aviation, refineries, healthcare, workplace and food quality (ASQ, 2011).RAMS assists in prioritizing system maintenance. These priorities will be given to those subsystems which has a high failure rate. The performance of system can be enhanced with RAMS analysis which utilized the best combination of failure and repair rate. If the system is unreliable and not available for long time then it reduces the efficiency of the plant. It leads to the failure of its production unit. RAMS plays an important role to reduce the cost of the plant which helps to achieve the break even point rapidly. Break-Even Analysis is best used as a preliminary planning tool. (Eti et al., 2006) minimized the system maintenance cost using the combination of RAMS. The break even analysis curve draws between cost and volume of product, when the plant is available for longer period of time than large production is done due to which time period is reduces to achieve the break-even point, similarly (R.C. Mishra et al., 2003) explains that maintenance in time can yield better cost control as compare to time- availability maintenance.

2. Literature Review

Among various tools and techniques for system performance modeling like FMEA, RAM, RCA, Quality Control Tools and RAMS etc. RAMS is considered as a tool which covers both engineering and management aspect of the plant. RAMS is a tool which evaluates the performance of system in design as well as in production stage. In this literature review, papers of last two decades are considered those include RAMS analysis using different tools and techniques.

Tsarouhas [2020] provided findings of RAM analysis of an ice cream industry. Mean Time Between Failure and Mean Time To Repair data of every system's equipment was obtained using Statistical and Pareto analysis. These data were collected from the maintenance log book of the plant which helps to further improve the performance of the plant. Moreover, this approach evaluates the next move of the engineers and managers with respect to the availability of the system.

Kumar et al. [2020] analysed the performance behavior of the Veneer layup system of a plywood manufacturing plant in terms of its operational availability. Petri Nets technique was used for modeling. The impact of the failure and repair rates of different subsystem on the availability of the system was investigated. Based on the results obtained they identified most critical subsystems which needs to be put on priority. The outcomes provide appropriate planning strategies to the maintenance engineers.

Swiderski et al. [2020] discussed semi-Markov and Markov models as one of the most popular tools to determine the system reliability. This works evaluate the individual effect of each element on the entire system which helps to calculate the total reliability of the system. In this comparison exponential form was assumed. The main focus was occurring on the inconsistencies obtained while preliminary assessment of the data is done and also on the diagnostics of the machine readiness.

Kumar et al. [2019] described an effort that has made to reduce the uncertainties and incidental shutdowns of the plant using RAM approach. In this work, Petri nets approach is used for performance modeling in a milk processing plant. They identified that centrifugal pump was the most critical subsystem. This paper also highlight that software used for modeling reduces the effort as compare to markov modeling. An attempt has been made to reduce the operation costs,

maintenance costs and enhance the production volume by providing proper maintenance strategies.

Berrouane et al. [2019] performed RAMS analysis using stochastic Petri nets modeling of oil and gas processing facilities. Small-sized P-N blocks are used to represent each component of the system. These blocks are communicated through Boolean algebra due to which structure become easily trackable and reduce the structural complexity of the system. This RAMS model is built with three solid features like time dependency, durability, and clear graphical structure.

Soltanali et al. [2018] discussed RAM approach in the automotive manufacturing industries. In this work, RAM analysis was occurred on the automotive assembly line which shows that forklift and loading equipments having the main bottlenecks on this line. This analysis helps to find the maintenance schedules which improve the availability of the plant.

Wu et al. [2018] introduced an approach using Safety Instrumented System (SIS) with time dependent failure rates for reliability assessment. Weibull distributions were adopted for modeling and failure rate evaluation done by Approximation formulas. Validation of modeling was done using Petri Nets.

Corvaro et al. [2017] provided a study on the reciprocating compressor systems which were used in the gas and oil processing plants. The study was based on the RAM analysis of each part of reciprocating compressor which affects the availability of the plant. The main aim of the study to provided the better maintenance planning as compare to previous ones, so that the availability of the plant is increases.

Bosseet al. [2016] described the multi-objective redundancy allocation problem for IT services where high availability was required by the customer. This deals with cost and availability using Monte Carlo and Petri Nets for solving these multi objective problems. The approach was used by IT services for their feasibility and suitability of design.

Zhang et al. [2015] considered reliability and cost simultaneously for the individual component under practical condition. Particle Swarm Optimization was used to solve this multi objective problem. A relation for interval-valued function was formed using interval-valued numbers. This approach presented in the case study of water management system by Super Supervisory Control and Data Acquisition (SCADA).

Mortezaet al. [2014] described the new methodology for complex system for reliability design. The simulation and modeling of the system was accomplished using Monte Carlo and Reliability Block Diagram (RBD) method, this methodology evaluates availability and reliability of the system in the design stage. Drilling equipment was used for testing the proposed methodology which verifies the failure and repair data for evaluating the performance of the systems.

Ravinder et al. [2014] presented the performance of a 210 MW thermal power plant. Both economic and thermodynamics analysis were carried out to predicted mass flow of steam, equipment cost, fuel cost, consumption rate of coal and overall thermal efficiency of the plant. This works found that the effect of condensate extraction pump was more sensitive than boiler feed pump on net present value.

Liu et al. [2013] discussed double 2-out-of-2 system which obtained time dependent safety and reliability of the system. Markov modeling was used to evaluate the performance analysis of the system. This work concluded that safety and reliability affects by weak diagnostic as compare to common cause of failure

Wolde et al. [2013] stated the inspections and maintenance problem of railway carriers. This research relates failure and repair rate with the performance of a system using mathematical modeling. This modeling was applied to any system to evaluate inspection plans which further optimized its cost.

Kumar et al. [2012] evaluated the availability of a thermal power plant using markovian approach. This simulation model was used to predict the performance of the system using failure and repair rates of their subsystems. The availability of the power plant may be further increased with providing preventive maintenance for critical subsystems.

Vora et al. [2011] described stochastic and performance analysis of condensate system of a thermal plant. Markov model has been developed for six subsystems using transition diagram. This modeling evaluates the Performance level of each subsystem and finds the critical subsystem. These results help the management to take future decisions.

Andre and Vitali [2010] evaluated the availability of critical systems using Stochastic Petri Nets (SPN) model because Traditional methods to evaluate system reliability such as markov chain were not suited to the non-Poisson failures. This modeling was applied on the case study of electronics airbag controller which calculates the availability on demand.

Sachdeva et al. [2009] applied Petri nets (PN) and markovian approach for modeling and performance analysis for a feeding system of a paper industry respectively. PN used for modeling the active or standby equipments in the system. Methodology of this work provides a better maintenance planning to the management which reduced the operating and maintenance cost.

Gupta et al. [2008] analyzed the performance and provided a Decision Support System (DSS) for the feed water system of a thermal power plant. The DSS for this system were developed with the help of markovian approach. Such decision matrices can helps the maintenance department to evaluate the maintenance intervals.

Javad et al. [2007] identified the chokepoints in the system and find the critical subsystems in the crushing plant at a Bauxite Mine. This paper presents a case study of system comprises of six subsystems in which parameters such as Exponential, Lognormal and Weibull distributions had been considered using Weibull++6 version software. The results also show the reliability and availability analysis of the findings were very useful for maintenance decisions making.

Marseguerra et al. [2006] presented the methodology of RAMS analysis and performed reliability redundancy allocation and maintenance evaluation using Genetic Algorithm (GA). These multi-objective optimization problems were formulated for further analysis and evaluation.

Bertolini et al. [2006] described a technique which used Failure Mode, Effects & Criticality Analysis methodology. Reliability and maintenance policies were evaluated by Petri Nets simulation. This combination of FMECA and Petri Nets simulation for reliability modeling had been applied to an Italian oil refinery. This technique proving to be a very useful which further validated by maintenance experts.

Samrout et al. [2005] suggested to minimize the Preventive Maintenance (PM) cost using Ant Colony Optimization (ACO) of series–parallel systems. This works makes a comparison of an Ant Colony Algorithms and Classic Genetic Algorithm in detail. A hybrid algorithm was developed by the ACO and CGA combination which further evaluate the PM cost.

Rauzy [2004] reported the six methods which compute the time dependent probabilities of Markov models. The methods like full matrix exponentiation, Euler method, Runge-Kutta method and Adams-Bash forth multi-steps methods of order 2 and 4 were discussed in detail, which concluded the Markov graphs with up to millions of transitions can be handled on computers in today's world.

Elegbede and Adjallah [2003] discussed the multi-objective methodology based on GA based approach. An experimental plan was formulated which maximizing the availability and minimizing the cost of repairable simultaneously. The methodology has the following two main steps: (1) Working out a plan for calibrating the parameter (2) Selection and implementation of the GA parameters.

Avontur et al. [2002] presented reliability analysis of hydraulic and mechanical systems using finite element approach. A complete description of finite element approach was explained for these systems which show the solid and fluidic components with a single set of equations. These equations were also capable to describe non-linear behavior of the systems like non-return valves theory which produces comprehensive results for the designer.

Tang [2001] described a method which based on the concept of graph theory and Boolean algebra to determine the reliability in a process industry. The former approach used for derive the formula where as latter one was used for finding the failure interaction of two elements of the systems. This combined approach assessing the reliability of a complex system.

Cochran et al. [2001] discussed the decision making approach in the chemical plant availability during operation. This approach includes inspection routines and maintenance strategies. It uses generic Markov model which produce accurate results in exponential failure and repair rates.

Borgonovo et al. [2000] proposed the Monte Carlo modeling that suggested the flexible tool for the management and operation of plants such as system repair, renovation, aging, obsolescence etc. Economic constraints arising from safety and reliability requirements. This analysis evaluates the maintenance and operating procedures.

3. Research Gaps

In this section brief findings of literature are going to discuss using RAMS approach in the last two decades are:

1. Literature survey revealed that many researchers have done work on RAM approaches however the limited work is reported on RAMS. They generally neglect the important aspects of the plant i.e. safety. Safety is a paramount importance in any field as a harmless work environment, enhances the morale of team members working in any hazardous environment. To alleviate these conditions a separate Safety Instrumented System (SIS) has been installed in the plant. The SIS contains a set of hardware and software controls that are widely used in critical processes. SIS usually consists of logic solvers (s), sensors, final elements etc.
2. Many researchers reported their work to increase plant availability by adopting proper maintenance procedure. But few are reported the relation between the availability and break even analysis where as there is direct relationship between availability and break even analysis, when the plant is available for long time than break even point will achieve in short span of time.

3. From studying the literature survey it is found that several methods are used for quantitative and qualitative analysis of plant like reliability block diagram (RBD), fault tree analysis, Markov model, Petri nets etc. These methods have their own advantages and disadvantages like the **Markov chain** is a powerful modeling and analysis tool with robust applications in stochastic reliability and availability analysis. The major difficulty with this modeling approach is the explosion of a number of states even though it works with very small systems. **Petri Nets (PN)** contains Places, Transitions, Arcs, and Tokens. Tokens are stored locally on their places and these are travel from one place to another via arcs through transition. Petri nets have increased attention because of their simplicity and make a balance of modeling and decision-making power but increase the complexity of the system.
4. Generally, the RAMS approach used by the researchers in the operational stages of plant, very few reported in the design stages of the plant if this approach is used in design stages than availability of the plant is increases.

4. Conclusions And Future Scope

The critical overview of available literature show the usefulness of various RAMS tools and techniques applied in different plants, so as the cost of non availability of plant could be minimized. Every plant is divided into several systems or subsystems for appropriate maintenance planning which keeps the systems to remain available for long duration. The decision support framework under statistical analysis has been developed using various tools and techniques such as Reliability Hazard Analysis, Failure Mode and Effects Analysis (FMEA), Reliability Block Diagram, Fault Tree Analysis, Reliability Growth Analysis, Root Cause Analysis, Finite Element Analysis, Markov Analysis, Petri Nets etc. These techniques have their own advantages and disadvantages which has been discussion in the paper.

In future, time dependent failure and repair rates are consider which looks more appropriate to the plant because there is a continuous wear and tear occurs. Such problems are not sorted out by ordinary modeling and optimization techniques. Researchers can use such techniques like Genetic Algorithms (GA), Artificial Neutral Network (ANN), Particle Swam Optimization (PSO) and Fuzzy etc. to solve these multi objective optimization problems. These techniques are also merged with conventional modeling techniques to obtain multi objective optimization techniques like Markovian GA, Fuzzy Petri Nets approach etc. These techniques can be further programmed using MATLAB software. These newly developed modeling techniques can be applied in both design as well as operational stage to further increase the performability of the plant.

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References

[1] Avontuur G. C. and Werff K. V., "Systems reliability analysis of mechanical and hydraulic drive systems", Reliability Engineering and System Safety, 2002, pp. 121–130.
[2] Barabady J., Kumar U., "Reliability analysis of mining equipment: A case study of a crushing plant at Jajarm Bauxite Mine in Iran", Reliability Engineering and System Safety, 2007, pp. 647–653.

[3] Berrouane M., Khan F.,Kamil M., "Dynamic RAMS Analysis Using Advanced Probabilistic Approach", Chemical Engineering Transactions, Vol. 77, 2019, pp.2241-2246.

[4] Bertolini M. and Bevilacqua M., "Reliability design of industrial plants using Petri nets", Journal of Quality in Maintenance Engineering, Vol. 12, 2006, pp. 397-411.

[5] Borgonovo E., Marseguerra M., Zio E., "A Monte Carlo Methodological Approach to plant Availability Modeling with Maintenance, Aging and Obsolescence". Reliability Engineering and System Safety, Vol. 67, 2000, pp. 61–73.

[6] Bosse S., Splieth M. and Turowski K., "Multi-objective optimization of IT service availability and costs" Reliability Engineering and System, 2016, pp.142–155.

[7] Cochran K.J., Murugan A. and Krishnamurthy," Generic markov models for availability, estimation and failure characterization in petroleum refineries". Computers and Operations Research, 2001, pp. 1–12.

[8] Corvaro F., Giacchetta G.,Marchetti B. and Recanati M., "Reliability, Availability, Maintainability (RAM) study, on reciprocating compressors API 618", ADVS, Vol.3, 2017, pp.266-272.

[9] Ebrahimi N.B., "Indirect assessment of System Reliability", IEEE Transactions on Reliability, Vol. 52, 2003.

[10] Gupta S. and Tewari P. C., "Simulation model for stochastic analysis and performance evaluation of steam generator system of a thermal power plant", International Journal of Engineering Science and Technology, Vol. 3, 2011, pp. 5141-5149.

[11] Gupta S., Tewari P.C. and Sharma A.K., "A Performance Modeling and Decision Support System for a pp. Feed Water Unit of a Thermal Power Plant", South African Journal of Industrial Engineering, Vol. 19(2), 2008, 125-134.

[12] Hameeda Z., Vatna J., "Important challenges for 10 MW reference wind turbine from RAMS perspective", Energy Procedia, 2012, pp. 263 – 270.

[13] Kleyner A., Volovoi V.,"Application of Petri nets to reliability prediction of occupant safety systems with partial detection and repair", Reliability Engineering and System Safety,2010.

[14] Kumar N., Tewari P.C. and Sachdeva A., "Petri Nets Modeling and Analysis of the Veneer Layup System of Plywood Manufacturing Plant" Engineering modeling 2020, pp. 95-107.

[15] Kumar N., Tewari P.C. and Sachdeva A., "Performance Modeling and Analysis of Refrigeration System of a Milk Processing Plant using Petri Nets", IJPE, 2019,Vol. 15, pp. 1751-1759.

[16] Kumar R., Sharma A. and Tewari P. C., "Thermal Performance and Economic Analysis of 210MW Coal-Fired Power Plant", Journal of Thermodynamics, 2014, pp.1-10.

[17] Kumar R., Sharma A. and Tewari P. C., "Markov approach to evaluate the availability simulation model for power generation system in a thermal power plant", International Journal of Industrial Engineering Computations, Vol. 3, 2012, pp.743–750.

[18] Laibin S., Mary Z., Yiliu A. and Zheng L. W., "Reliability assessment for final elements of SISs with time dependent failures" Journal of Loss Prevention in the Process Industries, Vol. 51, 2018, pp. 186-199.

[19] Liu Z., Liu Y., Cai B., Li J. and Tian X., "Markov Modeling of Double 2-out-of-2 System with Imperfect Detection and Common Cause Failures", International Conference on Computer, Networks and Communication Engineering, 2013.

[20] Marseguerraa M., Zioa E. and Martorell S., "Basics of genetic algorithms optimization for RAMS applications", Reliability Engineering and System Safety, Vol. 91, 2006, pp. 977–991.

[21] Rauzy A., "An experimental study on iterative methods to compute transient solutions of large Markov models", Reliability Engineering and System Safety, Vol.86, 2004, pp.105–115.

[22] Sachdeva A., Kumar P. and Kumar D., "Behavioral and performance analysis of feeding system using stochastic reward petri nets", IJAT, 2009, pp.156-169.

[23] Samrouta M., Yalaouia F., Chateleta E. and Chebbo N., "New methods to minimize the preventive maintenance cost of series–parallel systems using ant colony optimization", Reliability Engineering and System Safety, 2005, pp. 346–354.

[24] Saraswat S. and Yadava G.S., "An overview on reliability, availability, maintainability and supportability (RAMS) engineering", International Journal of Quality &Reliability Management, Vol. 25 No. 3, 2008, pp. 330-344.

[25] Soleimani M., Mohammad P., Rostami A., and Ghanbari A., "Design for Reliability of Complex System: Case Study of Horizontal Drilling Equipment with Limited Failure Data", Journal of Quality and Reliability Engineering, 2014.

[26] Soltanali H., Garmabaki A., Thaduri A., Parida A.,Kumar U. and Rohani A.,"Sustainable production process: An application of reliability, availability, and maintainability methodologies in automotive manufacturing", Journal of Risk and Reliability, 2018, pp.1-16.

[27] Swiderski A., Borucka A., Grzelak M. and Gil L., "Evaluation of Machinery Readiness Using Semi-Markov Processes", Appl. Sci. 2020, Vol.10, pp.1-15.

[28] Tang J., "Mechanical system reliability analysis using a combination of graph theory and Boolean function", Reliability Engineering and System Safety, Vol. 72, 2001, pp. 21-30.

[29] Tsarouhas P., "Reliability, Availability, and Maintainability (RAM) Study of an Ice Cream Industry", Appl. Sci. 2020, Vol.10, pp.1-20.

[30] Wolde M., Ghobbar A., "Optimizing inspection intervals Reliability and availability in terms of a cost model: A case study on railway carriers", Reliability Engineering and System Safety, 2013, pp. 137–147.

[31] Zhang E., Chen Q., "Multi-objective reliability redundancy allocation in an interval Environment using particle swarm optimization", Reliability Engineering and System Safety, 2015, pp. 83–92.