A REVIEW ON THE RELIABILITY, AVAILABILITY AND MAINTAINABILITY (RAM) APPROACHES IN CONCEPTUAL PROCESS DESIGN

Narendra Kumar and P. C. Tewari
Department of Mechanical Engineering, National Institute of Technology, Kurukshetra-136119, INDIA
narendra_6160054@nitkkr.ac.in, pctewari1@rediffmail.com

Abstract: This paper critically investigates the various factors which influence the overall availability of the manufacturing plant. It also describes the different RAM tools, techniques and methods which are qualitative, quantitative and commercially available software(s) to support RAM studies and the integrated current approaches in conceptual process design. A number of concerned literatures taken from the last few decades that provide a detailed survey of topics including reliability-availability analysis methods. In the last section of paper, an attempt is also made to give directive model for research on focused area using an optimal reliability tools under certain resource constraints.

Key words: RAM Tools, Complex Process, Decision support system, Simulation.

1. INTRODUCTION: The changing business environment and a long list of failures and associated effects from history sheet drawn the attention of business leaders and practitioners to find the ways of cost savings, revenue improvement, safe and highly reliable quality product available on demand. An estimate says the revenue lost due to unexpected shutdowns of plant can range from \$500-\$100000 per hour (Tan and Kramer, 1997). This paper focused on RAM tools that include variety of methods, both qualitative and quantitative, and commercially available software supporting RAM studies.

Reliability is the ability of an item to perform a required function, under given environmental and operational conditions and for stated period of time (BS4778,1991).

Maintainability is the ability of an item, under stated conditions of use, to be retained in, or restored to a state in which it can perform its required functions when maintenance is performed under stated conditions and using prescribed procedures and resources (BS4778, 1991). **Availability**, in general, is defined as the ability of an item to perform its required function at a stated instant of a time or over a stated period of time (BS4778, 1991). Plant availability is a function of the reliability and maintainability i.e., A=f(R, M). Therefore, it is clear from the definition of availability that a process engineer can improve the plant availability at the design stage by either increasing reliability or maintainability or both. **Complex systems** are characterized by large network of links between components or by statistical dependence between the component states. Some typical examples of process industries having complex systems are food, beverage, chemical, pharmaceutical, consumer packaged goods, biotechnology industries, gas-and power-distribution etc(Narendra & Tewari,2016).

2. LITERATURE SURVEY AND REVIEW

In literature a number of review papers have appeared in the last few decades that provide a detailed survey of topics that include reliability-availability analysis methods.

Poh and Liang[2017]developed multiple criteria decision support to build a comprehensive analytic network process model that will adequately capture and reveal all the interrelationships and interdependency among the elements in the problem, which is often a very difficult task.

Asjad and Khan [2016] did thorough analysis of maintenance cost for an asset and applied genetic algorithm to optimize the maintenance cost for higher performance (i.e. availability).

Ranjan et al. [2015] proposed a competing risk model based on of gamma and exponential failures where the gamma reflects aging failures and exponential corresponds to accidental failures. The proposed model is analyzed in a Bayesian framework using Markov chain and Monte Carlo simulation. They concluded that if the failures are dominated by aging, the probability distribution function (pdf) curve of proposed model-S will be closer to that of gamma model. On the other hand, if the failures are dominated by the accidents, the corresponding curve-S will be closer to that of exponential distribution.

Kumar et al. [2015] did a significant review of literatures on reliability engineering and they found wide scope for the newly developed methods, software's, techniques' and models such as, Petri net, Markov models, Artificial Bees' Colony (ABC) algorithm and Optimal Computing Budget Allocation (OCBA).

Doostparast et al. [2014] developed a reliability based periodic preventive maintenance planning model for systems to minimize the total maintenance cost using simulated annealing approach. Decision Support System was developed for feeding unit of a sugar industry, so as to decide the maintenance priorities among its various subsystems.

Kim and Kang [2013] proposed a non-simulation-based network reliability analysis method based on the Recursive Decomposition Algorithm (RDA) for risk assessment of generic networks such as transportation, water supply, sewers, telecommunications, and electrical and gas networks whose operation is defined by the connections of multiple initial and terminal node pairs.

G. Thangamani [2012] used petri nets to deals with the availability analysis is of a Lube oil system used in a combined cycle power plant. The system is modeled as a Generalized Stochastic Petri Net (GSPN) taking into consideration of partial failures of their subsystems and common-cause failures; analyzed using Monte Carlo Simulation approach. The major benefit of GSPN approach is hardware, software and human behavior can be modeled using the same language and hence more suitable to model complex system like power plants.

Kajal and Tewari [2012] did performance optimization of a milk plant using genetic algorithm technique. The mathematical formulation is carried out using probabilistic approach and the Markov birth-death process is used to develop the differential equations. The steady state availability expression has been derived using normalizing conditions. The optimal values of failure/repair rates of each subsystem of the skim milk powder unit have been evaluated by using Matlab software tool.

Vora Y. et al. [2011] presented the stochastic analysis and performance evaluation of steam generator system of thermal power plant. Initially transition diagram representing the operational behavior has been drawn and problem addressed by using Markov approach. The availability of each system has been analyzed and condition based maintenance decisions has been proposed.

Khanduja R. et al. [2010] have dealt with the mathematical modeling and performance optimization for the paper making system in a paper plant using genetic algorithm. Considering exponential distribution for the probable failures and repairs, the mathematical formulation of the problem is done using probabilistic approach and differential equations are developed based on Markov birth-death process. These equations are then solved using normalizing conditions to determine the steady state availability of the paper making system.

Kumar S.et al. [2009] discussed the performance evaluation and availability analysis of ammonia synthesis unit of a fertilizer plant based on Markov Birth-Death process using probabilistic approach.

Sachdeva A. et al. [2008] described a new multi criteria optimization framework for deriving optimal maintenance schedules for preventive maintenance which considers availability, maintenance cost and life cycle costs as the criteria for optimization using Petri Net.

Gupta et al. [2007] computed the reliability, availability, and mean time before failure of the process of a plastic-pipe manufacturing plant consisting of a (K, N) system for various choices of failure and repair rates of sub-systems. They proposed a matrix calculus method using MATLAB software to find out the reliability of the plant. The outcomes reveals that analysis of reliability, long-run availability and mean time before failure of the butter-oil manufacturing plant can help in increasing the production and quality of the butter-oil. This approach can be implemented to find reliability of other manufacturing plants as well.

Marseguerra M. et al. [2006] discussed the use of Genetic Algorithms (GA) within the area of Reliability, Availability, Maintainability and Safety (RAMS) optimization. First, the multi-objective optimization problem has been formulated in general terms and two alternative approaches to its solution are illustrated.

Samrout M. et al. [2005] have proposed a new method to minimize the preventive maintenance cost of series–parallel systems by developing a new method based on Ant Colony Optimization (ACO) technique.

Ramirez-Marquez J.E. and Coit D.W. [2004] studied a Multi-state Series-Parallel System (MSPS) with capacitated binary components that can provide different multi-state system performance levels. They state that different demand levels, which must be supplied during the system operating period, result in the multi-state nature of the system and the new solution methodology offers several distinct benefits.

Ebrahimi N.B. [2003] developed the techniques for assessing system reliability relies heavily on failure data. Also focused on a method that assesses the reliability of a system, which has extremely high reliable components/systems, for which it is difficult to collect failure data. **Elegbede C. and Adjallah K. [2003]** described a methodology based on Genetic Algorithms (GA) and experiments plan to optimize the availability and the cost of repairable parallel-series systems.

Arulmozhi G. [2002] proposed an expression and an algorithm for computing reliability of K-out-of-N system. The author states that it is an easy to implement, fast and memory efficient algorithm and helps to improve the computational efficiency considerably.

Avontuur G.C. and Werff K. V. [2002] presented a new method based on finite element equations, for systems reliability analysis of mechanical and hydraulic systems.

Tang J. [2001] proposed a new method based on graph theory and Boolean function for assessing reliability of mechanical systems. Firstly, by using the graph theory, the formula for the reliability of a mechanical system that considers the interrelations of subsystems or components generated and then Boolean function has been used to examine the failure interactions of two particular elements of the system.

Borgonovo et al. [2000] presented a Monte Carlo approach for the evaluation of plant maintenance strategies and operating procedures under economic constraints. It provides a flexible tool which enables one to describe many of the relevant aspects for plant management and operation such as aging, repair, obsolescence, renovation, which are not easily captured by analytical models.

Wakefield et al.[1998] describes the Petri Net approach to modeling and shows how good dynamic models of automated construction systems can be developed. Several common Petri Net structures and features useful in construction system modeling are described Time and colour Petri Nets and their application in modeling specific characteristics of construction systems are discussed.

Narahari and Vishwanadham [1985] present an approach for modeling and analyzing flexible manufacturing systems (FMSs) using Petri nets. first build a Petri net model (PNM) of the given FMS in a bottom-up fashion and then analyze important qualitative aspects of FMS behavior such as existence/absence of dead-locks and buffer overflows.
Conceptual process design and different approaches are discussed in more detail in
Grossmann, (1997); Herder, (1999); Meeuse, (2003) discussed and presented more detail about conceptual process design and different approaches.

3. CURRENT APPROACHES IN RAM STUDIES

In this section a brief overview is provided of various methods and tools that can be used by a researcher at the conceptual design and operational stage. The current approaches to integrating RAM in process design are categorized into the sequential and the simultaneous approaches. The sequential approach separates the process design activity from the reliability analysis to find improvements in plant availability. The various RAM tools comprising of reliability-availability methods which can be broadly classified as measurement based and model based methods (Sathaye et al., 2000).It can be shown in figure 1.

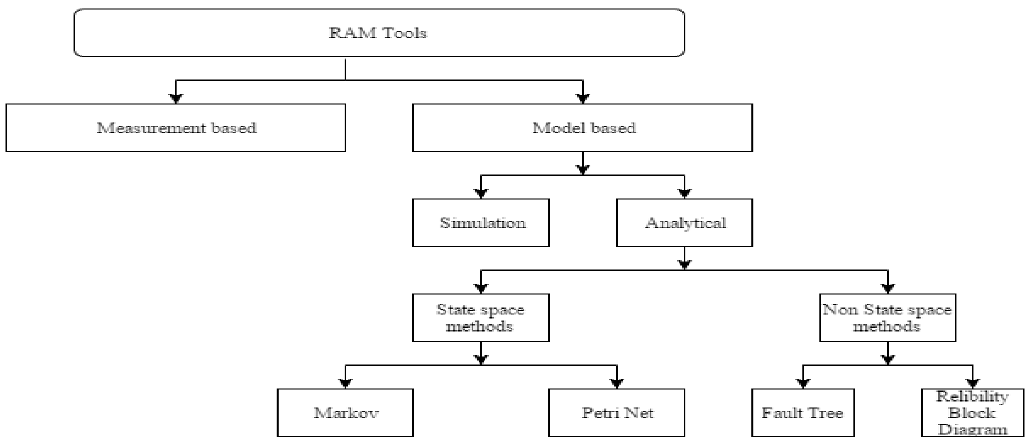

Fig. 1: Reliability Availability Analysis Methods/Techniques

Measurement based methods require building a real system or its prototype and taking measurements and then analyzing the data statistically. At the operational stage it can prove to be very expensive to inject faults into a real system to measure data. Model based methods are particularly useful at the design stage to screen lots of design alternatives without building the actual system. Model-based methods can be further categorized into simulation methods and analytical methods, both require a system model to be constructed in terms of random variables for the state of the underlying units (Dekker, 1996). The simulation method uses a probability distribution function for equipment failure and repair actions and uses a simulation engine (usually a Monte Carlo simulation engine) to simulate the detailed dynamic behavior of the system and evaluate the required measures. Analytical methods use analyticalmodels that consist of sets of equations describing the system behavior . A number of analytical methods have been developed which can be broadly categorized into state space or nonstate space modelling techniques (Sathaye et al., 2000).

Fault tree analysis techniques, first developed in 1962 at Bell Telephone Laboratory. A fault tree is a pictorial representation of logical relationships between events and it can be used to represent a combination of events that will lead to system failure, called as top event.

A reliability block diagram(RBD) is a graphical representation of how the components of a system are connected reliability-wise. The simplest and most elementary configurations of an RBD are the series and parallel configurations. In a reliability block diagram each component of the system is represented as a block that is connected in series, and/or parallel, based on the operational dependency between the components. The non-state models described above cannot easily handle more complex situations such as failure/repair dependencies, shared repair facilities, different types of maintenance for different units with different effects and different resource requirements. In such cases,more detailed models such as the Markov chain model and Petri net models can be used.

The Markov model provides a powerful modelling and analysis technique with strong applications in time-based reliability and availability analysis. The major disadvantage of Markov modelling is an explosion of the number of states even when dealing with relatively small systems.

A Petri net is a directed-graph (digraph) consisting of places, transitions, arcs and tokens. Tokens are stored in places and moves from one place to another along arcs through transitions. A marking is an assignment of tokens to the places and these may change during the execution of a Petri net. If the transition firing times are stochastically timed, the Petri net is called a stochastic Petri net (SPN). Simulation methods are very flexible and can provide accurate predictions for system perform measures. The number of simulation runs required for accurate availability measure results will depend on the variation in the output measure at each run. In the last decade, a numbers of authors have published papers have on the successful application of simulation methods for availability analysis of industrial systems. Thangamani et al. (1995) assessed the availability of the fluid catalytic cracking unit (FCCU) of a refinery by using fault tree to model the system and Monte Carlo simulation to simulate the results. Cochran et al. (2001) have provided availability simulation results for the FCCU unit using Petri net and generic Markov chain models for the system analysis.

4. BARRIERS IN RAM STUDIES

In spite of lot of different methods are available for reliability estimation and improvement, however Small and Medium Enterprises (SMEs) often encounter difficulties to implement RAM principles due to problems from both sides either management or engineering side. Here authors presented some common challenges of implementing RAM tools as listed below

4.1 Barriers from Engineering Side

- Inadequate knowledge or understanding of Reliability ineffective measurement techniques and lack of access to data and result.
- Difficulties to collect data from vendors
- Lack of up to date training and education
- Inappropriate condition for implementing reliability assessments
- Inadequate use of empowerment and teamwork
- Data collection is time consuming
- There is a lack of structured and quantitative approach to manage reliability, availability and maintenance measures throughout the life span of plants.
- The existing quantitative maintenance optimization methods are considered to be too complex and insufficient to handle practical real world conditions in industry.

4.2 Barriers from Management Side

- Lack of top management commitment
- Inability to change organization culture
- Improper planning
- Inability to build a learning organization that provides for continuous improvement
- Software tools, it often requires significant investments.

5. CONCLUSIONS AND PROPOSED RAM MODEL FOR RESEARCHER

The detailed overview of literature highlights the various RAM issues, tools and techniques applied in different phases of process industries so, that high cost of failures can be prevented. These tools are newly developed models, software's, and optimization techniques applicable at the process design as well as the operational stage. The literatures taken are predominant with two kinds of approaches that are: reliability approach and maintenance approach. In Reliability, the focus is only on those alternatives that improve the system availability where as in the maintenance focus is on minimal repair policy. Finally, an attempt has been made by the authors to provide a directive model for reliability engineers and industry leaders involved in RAM practice with an optimal reliability tools under certain resource constraints.

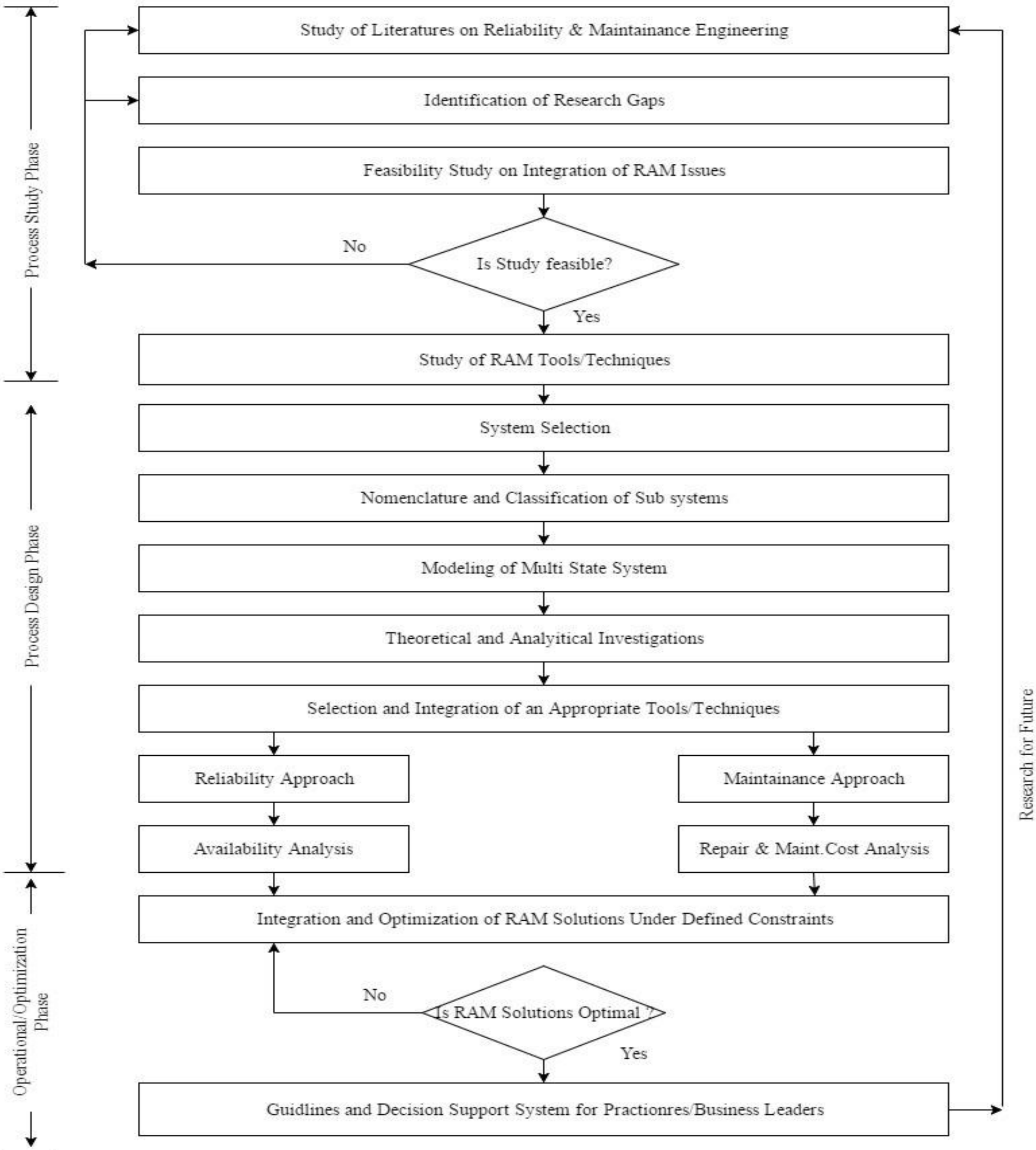

Fig.2 Methodology for RAM Study

Biographies

Narendra Kumar is a Ph.D Scholar at Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, India. He earned B.E. in Industrial and Production Engineering from Visweswaraya Technological University, Belagaum, India and M.Tech in Industrial Engineering from National Institute of Technology, Jalandhar, India. He has published journal and conference papers. His research interests include manufacturing, simulation, optimization, reliability, scheduling, manufacturing, and lean. In addition to carrying out the Ph.D. research, he also supervised a Master project for a mechanical engineering.

student.He is a life member of Indian Institution of Industrial Engineering (IIIE), Mumbai,India.

P.C.Tewari is a Professor at Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, India. Professor Tewari holds Bachelor of Science in mathematics, B.E. (Industrial Engineering), University of Roorkee, Roorkee , M.E. (Mech. Engg.), University of Roorkee, Roorkee(Now IIT, Roorkee). He contributed to more than 200 National and International Journals/ Conferences and recently Chaired a Technical Session, presented a Research Paper and felicitated with **"Best Presentation Award"** in International Conference on Industrial Engineering (ICIE-2016) at Kuala Lumpur, Malaysia from 18th August to 19th August, 2016**.** He is also working as social activist and rendering responsibility Chief Coordinator of Shiksha Abhiyan of N.I.T.K., a prime initiative towards Institute Social Responsibility for under privileged children of poor sections of the Society. He is a life member of Life Member of Indian Society of Technical Education **(ISTE)**, and Indian Society for Theoretical & Applied Mechanics **(ISTAM)**.

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