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Predicting uncertain behavior of press unit in a paper industry using artificial bee colony and fuzzy Lambda–Tau methodology

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ABSTRACT

As the industrial systems are growing complex these-days and data related to the system performance are recorded/collected from various resources under various practical constraints. If the collected data are used as such in the analysis, then they have high range of uncertainties occurred in the analysis and hence performance of the system cannot be done up to desired levels. Thus the main objective of the present work is to remove the uncertainties in the data up to a desired degree of accuracy by utilizing the uncertain, vague and limited data. For analysis of this, an artificial bee colony based Lambda–Tau (ABCBLT) methodology has been used in which expression of the reliability parameters are computed by using Lambda–Tau methodology and their membership functions are formulated by solving a nonlinear optimization problem with artificial bee colony (ABC) algorithm. A time varying failure rate has been used in the analysis instead of constant failure rate. A new RAM-Index has been proposed for ranking the systems' components based on its performance. The technique has been demonstrated through a case study of press unit of a paper industry, situated in Northern part of India, producing 200 tons of paper per day. The results computed by the proposed approach are compared with the Lambda–Tau methodology and concluded that they have a reduced region of prediction in comparison of existing technique region, i.e. uncertainties involved in the analysis are reduced. Thus, it may be a more useful analysis tool to assess the current system conditions and involved uncertainties.

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, thermal, paper, 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. But unfortunately, failure is an unavoidable phenomenon associated with technological products and systems. Over time, however, a given system suffers failures and 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. To improve the quality and quantity of a manufacturing related curriculum, there is need to emphasize more on operational management. For this reason, there is a growing interest in implementation and investigation of reliability, availability and maintainability (RAM) principles in various industrial systems during last four decades. This is especially true in the process industry, characterized by expensive and specialized equipment along with stringent environmental constraints. The job of maintenance engineers becomes more challenging as they attempt to study, characterize, measure and analyze the behavior and performance of the process systems.

Zerwick [1] pointed out in the context of pressure vessels that a systematic strategy based on RAM principles helps to evaluate changes in inspection frequency, maintenance actions or condition monitoring strategies leading to decrease in frequency of planned shut downs, increase of time period between statutory inspections, and reduction in maintenance cost. Blischke and Murthy [2] reported 26 cases on reliability and maintainability and statistical techniques illustrated included modeling, reliability assessment and prediction, simulation, testing, failure analysis, failure mode and effects analysis (FMEA), use of expert judgment, preventive

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maintenance, statistical process control, regression analysis, reliability growth modeling and analysis, repair policy, availability analysis, and many others. Liberopoulos and Tsarouhas [3] reported a case study of speeding up a croissant production line, based on actual data collected over ten months, by inserting an in-process buffer in the middle of the line to absorb some of the downtime, based on the simplifying assumption that the failure and repair times of the workstations of the lines have exponential distributions. Barabady [4] analyzed the operating reliability and availability for a system with periodically inspected and maintained components subjected to some maintenance strategy and find some importance measures that show the criticality of the components or subsystems. Rajpal et al. [5] introduced a composite measure of reliability, availability and maintainability in the form of a RAM-Index for measuring the system performance. They developed an artificial neural network (ANN) model for assessing the effect of input parameters on RAM-Index of a repairable system namely a helicopter. They used historical data to train the ANN. Their RAM-Index is static i.e. its value depends on constituents parameters' values at specified times. Sachdeva [6] analyzed, planed and optimized the RAM aspects in an industrial system by using PN. Herder et al. [7] built a RAM model, based on RBD with Monte Carlo simulation engine, for an Industrial plant. Sharma and Kumar [8] model the performance of a urea plant using RAM analysis by applying Markovian approach. They utilized crisp historical data without quantification of involved uncertainties. Saraswat and Yadava [9] reviewed the literature on reliability, availability, maintainability and safety (RAMS) engineering. They provided the information about the current and past scenario of RAMS engineering in research and industry. Garg and Sharma [10] developed two phase approach for analyzing the reliability and maintainability of an industrial systems. In their first phase, the parameters of their respective distributions are estimated from the collected or historical data while in second phase their optimal values are obtained by using particle swarm optimization (PSO) technique.

All of them have used the historical data, which are available either from historical record or collected form the various resources, in the form of crisp data for evaluating the RAM parameters. But unfortunately the available data, in the form of failure and repair rates, represents the past behavior of the system but unable to predict the future behavior of the system. To estimate the failure and repair rates/times more accurately, a large quantity of data will required. But it is difficult to obtain such large amount of data from any particular plant due to rare events of components, human error and economic restraints. However, in the real world problems, there exist a large amount of uncertainties in the collected or available (historical) data which affect each part/unit of the system differently, and thus the issue is subject to uncertainty. Thus, the probabilistic approach to the conventional reliability analysis is inadequate to account for such built-in uncertainties in the data. For this reason, the concept of fuzzy reliability have been introduced and formulated in the context of possibility measures [11]. Thus there needs an appropriate approach for accessing and analyzing the behavior of the industrial system in terms of RAM. To this effect, Komal et al. [12] introduced the RAM-Index by utilizing the vague, imprecise and uncertain data. A constant failure rate model has been used during the formulation of RAM-Index and its parameters. In order to evaluate its RAM parameters and consequently to RAM-Index, there needs an efficient technique for analyzing the behavior of reliability parameter using limited, vague and imprecise data up to desired degree of accuracy. For this, an approach gave by Knezevic and Odoom [13] for analyzing the behavior of an industrial system by using Petri nets and fuzzy set theory may be used. By using this, a critical behavior of an industrial system has been analyzed by [14–16] by utilizing uncertain, vague and limited data. But it has been analyzed from their studies that when the system structure becomes large then the computed RAM parameters, in the form of fuzzy membership functions, have a wide range of spread due to the various fuzzy arithmetic operation involved in the calculation [17–19]. Thus this approach does not give the real trend of the system behavior when the data is imprecise and hence cannot be an efficient approach for calculating the RAM parameters. In order to take more sound decisions for improving the performance of the system, it is necessary that spread for each RAM parameter must be reduced up to a desired degree of accuracy so that plant personnel/decision makers may take their decision in smaller time.

Another shortcoming of the existing technique is that almost all the researchers used constant failure rate model of the system i.e. failure and repair rates/times follows the exponential distribution, for analyzing the behavior of the system. It seems that there is a need for a more generalized methodology that can be applied for variable rates [20,21]. Rani et al. [20] have highlighted these ideas and analyzed the behavior of complex repairable industrial system, by considering time varying failure rate i.e. failure rates follows Weibull distribution and constant repair time, in terms of various reliability parameters utilizing uncertain data. Triangular fuzzy numbers are used to quantify the involved uncertainties in the data. But in order to generalize the approach for large complex structural system, artificial bee colony based Lambda–Tau (ABCBLT) technique [21] has been used in the present study. ABCBLT is a soft computing based technique in which expression of the reliability indices are obtained by Lambda–Tau methodology while artificial bee colony (ABC) [22–24] is used to construct their membership functions by utilizing their quantified data of the system in the form of the triangular fuzzy numbers.

Thus, it is observed from the study that by using limited, vague and imprecise data, RAM parameters may be computed for a complex repairable industrial system. The objective of the present paper is divided into two folds- first is to quantify the uncertainties with the help of fuzzy numbers and to develop a technique to analyze the system's behavior more closely and to make the decisions more realistic and generic for further application while second is to analyze the effect of failure and repair pattern on to a composite measure of RAM-Index of industrial systems. A RAM-Index for a time varying failure rate has been introduced by considering reliability, availability and maintainability keys indices which influence the system performance directly and used historical uncertain data for its evolution. Major advantage of this index is that, by varying individual component's failure rate and repair time, the impact on the system's performance can be analyzed effectively to plan the future course of action. In order to demonstrate the approach, a RAM analysis of the press unit of a paper industry has been carried out. The results obtained by the proposed approach are compared with the Lambda–Tau methodology. These results may be helpful for plant personnel for analyzing the system behavior and may improve the system performance by adopting suitable maintenance strategies. The short version of this paper has been published in the proceedings of the online conference "World Conference on Soft Computing in Industrial Applications (WSC16)" [20].

2. Critical comments on reviewed literature

The following observations may be made after critically reviewing the literature: If their (above literature) approach and RAM-Index is used to analyze the behavior of industrial systems, then some obstacles are found during analysis.

1. First and basic shortcoming of the existing RAM-Index in the literature is that it is based on the components whose follows the constant failure rate model i.e. components of the