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Research Article

Performance analysis of complex repairable industrial systems using PSO and fuzzy confidence interval based methodology

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ABSTRACT

The main objective of the present paper is to propose a methodology for analyzing the behavior of the complex repairable industrial systems. In real-life situations, it is difficult to find the most optimal design policies for MTBF (mean time between failures), MTTR (mean time to repair) and related costs by utilizing available resources and uncertain data. For this, the availability–cost optimization model has been constructed for determining the optimal design parameters for improving the system design efficiency. The uncertainties in the data related to each component of the system are estimated with the help of fuzzy and statistical methodology in the form of the triangular fuzzy numbers. Using these data, the various reliability parameters, which affects the system performance, are obtained in the form of the fuzzy membership function by the proposed confidence interval based fuzzy Lambda-Tau (CIBFLT) methodology. The computed results by CIBFLT are compared with the existing fuzzy Lambda-Tau methodology. Sensitivity analysis on the system MTBF has also been addressed. The methodology has been illustrated through a case study of washing unit, the main part of the paper industry.

1. Introduction

An industrial system is composed of numerous components and the probability that the system survives depends directly on each of its constituent components. In industrial systems, equipments and manpower are used to convert raw material of relatively low value into finished products of higher value. For justifying the heavy investment made, it is desirable to keep these systems operative for a long duration of time. Thus, there is a need to develop a suitable methodology for analyzing the performance of these complex systems so that timely actions may be initiated for achieving the goal of high production and hence more profit. For repairable system, the availability is one of the more meaningful measures than reliability for measuring the effectiveness of the maintained systems, because it includes reliability as well as maintainability [1]. Generally, system reliability can be improved either by incremental improvements of component reliability or by provision of redundancy components in parallel; both methods result in an increase in system cost. Therefore, optimization methods are necessary to obtain allowable costs at the same time as high availability levels.

Under the series-parallel system framework, there are many methods to determine the optimal parameters of components, such as dynamic planning, integer programming, non-linear integer programming and heuristic or metaheuristic algorithms. But conventional methods, like gradient method, Lagranges multiplier method, branch and bound method, etc., require derivatives for all non-linear constraint functions that are not derived easily because of the high computational complexity. Thus conventional methods do not give the optimal result of the problem as it acquires local solution. To overcome this difficulty and to get a global solution, genetic algorithm (GA) and particle swarm optimization (PSO), etc., as a member of metaheuristics algorithm, have proved themselves to be able to approaching optimal solution against any problem. A lot of researchers have investigated the theoretical problems of availability, reliability and cost modeling and their corresponding studies on the specific applications by GA [2–6] and PSO [7–12]. Additionally, there are some other types of reliability problems developed by the researchers such as distribution system reliability [13], reliability of dynamic systems [14], reliability and maintainability optimization [15] and so on. Apart from the reliability and/or availability modeling for obtaining the desired values of the system parameter, it is necessary that the system should run failure free within a limited time period so as to increase its performance with some suitable maintenance strategies. However, failure is nearly an unavoidable phenomenon in mechanical systems/components. These failures may be due to the result of human error, poor maintenance,or inadequate testing and inspection. Thus, the job of the system analysts has become more challenging as they have to study,

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characterize, measure and analyze the uncertain systems' behavior, using various techniques like Markovian approach, fault tree analysis (FTA), reliability block diagrams (RBD), Petri nets (PN), etc. All of them have used the historical data which are either out of date or collected under different operating and environmental conditions. Thus, the used data were vague, imprecise, and uncertain, i.e. historical records can only represent the past behavior but may be unable to predict future behavior of the equipment. Therefore, it may be very difficult to construct an accurate and complete mathematical model for the system. Thus, one comes across the problem of uncertainty in reliability assessment. In such circumstances, it is usually not easy to analyze the behavior and performance of these systems up to desired degree of accuracy by utilizing available resources, data, and information. If the data are used as such in the calculations, the results will be highly uncertain. Thus, the probabilistic approach to the conventional reliability analysis is inadequate to account for such built-in uncertainties in the data. On the other hand, fuzzy methodology can deal with imprecise, uncertain dependent information related to system performance and provides a better, consistent and mathematically more sound method for handling uncertainties in data than conventional methods, such as Markov process, Bayesian statistics, etc. The concept of fuzzy set theory and fuzzy arithmetic has been used in the evaluation of the reliability of the system by the various researchers [12,16–20]. Yao et al. [21] applied a statistical methodology in fuzzy system reliability analysis and got a fuzzy estimation of reliability. Jamkhaneh et al. [22] considered the fuzzy reliability of both series and parallel systems using fuzzy confidence interval.

Furthermore, only reliability index, as discussed by above researchers, is inadequate to give deeper idea about such type of systems' behavior because a lot of factors exist which overall influence the systems performance and consequently their behavior. Therefore, to analyze more closely the systems' behavior, other reliability criteria should be included in the traditional analysis and involved uncertainties must be quantified. The inclusion of various reliability indices as a criterion helps the management to understand the effect of increasing/decreasing the failure and repair rates of a particular component or subsystem upon the overall performance of the system and the quantification of uncertainties provides results closer to the real situational environment's results. In that direction Refs. [23,25,24] have analyzed the behavior of the repairable industrial systems using PN and fuzzy approach. Sharma et al. [26] have analyzed the behavior of the washing unit of a paper mill using GA and fuzzy approach. In these studies more emphasis has been given to the evaluation of different reliability indices, reflecting system behavior, in the form of fuzzy membership functions. Triangular fuzzy numbers (TFNs) are developed by using fuzzy possibility theory for removing the uncertainty in the available/collected data while Petri net (PN) has been used for modeling and analysing complex industrial systems and process due to its ability to model the dynamic of the system. But the disadvantage of their technique is that they had not found the estimation of reliability index in the fuzzy sense. Furthermore, they neither use fuzzy data nor the robust and comprehensive fuzzy confidence interval. Since, the population of reliability parameters of the subsystem is unknown, therefore using sampling, it is desirable to use the statistical confidence interval for the estimation of reliability parameters. To tackle this problem, we proposed a new method for reliability evaluation for the repairable industrial system by using both fuzzy data and comprehensive fuzzy confidence interval.

Thus, the main objective of the present paper is to analyze the behavior of the complex repairable industrial system by utilizing the vague, uncertain and imprecise data. For this a methodology has been proposed in two phases. In the first phase, the data related to system components in the form of MTBF and MTTR i.e. failure rate and repair time are obtained by constructing their availability–cost model. This model is solved with the PSO for getting the optimal values of MTBF and MTTR. In order to increase the performance and efficiency of the system, the obtained optimal values of MTBF and MTTR are used in the next phase i.e. in phase II. In phase II, a methodology named as confidence interval based fuzzy Lambda-Tau (CIBFLT) has been proposed for analyzing the behavior of the complex repairable industrial system in the form of various reliability parameters. The proposed methodology involves qualitative modeling using PN and quantitative analysis using lambda–tau method of solution with basic events represented by fuzzy numbers of triangular membership functions through statistical estimation technique and data records. To strengthen the analysis various reliability indices such as system's failure rate, repair time, MTBF, reliability, availability and expected number of failures are computed in the form of fuzzy membership functions. The membership functions of reliability indices are built based on statistics and fuzzy set theory. Results obtained from CIBFLT technique are compared with the lambda–tau results. The obtained results will help the management for reallocating the resources to achieve the targeted goals of higher profit.

2. Methodology

The main objective of the work is to remove the uncertainty in the data up to a desired degree of accuracy. For this a methodology, named as confidence interval based fuzzy Lambda-Tau (CIBFLT) has been proposed in this section. The methodology is divided into two phases. In the first phase, the data related to systems component are obtained from their availability–cost optimization model by considering availability function, and their corresponding components' manufacturing and repairing costs and solved through meta-heuristic technique named as PSO. In the second phase, various reliability parameters are obtained by using CIBFLT methodology and their results are compared with the existing fuzzy Lambda-Tau (FLT) methodology. The detail description of the methodology is described as below.

2.1. Phase I: Formulation of optimization model of the system

As the collected information from the various resources/history is very much dependent on the system configuration/structure, it is very difficult to analyze the system behavior correctly. Also the collected data/records represent only the past behavior of the system but are unable to predict the future behavior of the system. Thus in order to find the optimal parameter of the availability parameters i.e. MTBF and MTTR, the system availability optimization model is formulated by assuming the following assumptions:

(i) The components are operated independently, i.e. the failure and repair characteristics of the components are statistically independent.
(ii) The failure and repair rate are constants i.e. they obey exponential distribution.
(iii) There is no simultaneous failures among the subsystems.
(iv) Separate maintenance facility is available for each component and repair component is considered AGAN (as good as new).

2.1.1. Expression for availability of the system

The basic expressions for availability, failure rate and repair rate for a series–parallel system obtained from their reliability