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Behavior prediction of washing system in a paper industry using GA and fuzzy lambda–tau technique

S.P. Sharma [a], Dinesh Kumar [b], Ajay Kumar [c,*]

[a] Department of Mathematics, Indian Institute of Technology, Roorkee 247667, Uttarakhand, India
[b] Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee 247667, Uttarakhand, India
[c] Department of Applied Mathematics, ABV-Indian Institute of Information Technology and Management Gwalior, Gwalior 474010, Madhya Pradesh, India

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ABSTRACT

Availability analysis has been an important issue in the design field of any Industrial system as the system structure has become more complicated. Also, the system availability is affected by many factors such as design, manufacturing, installation, etc., and so it may be extremely difficult to model, analyze and predict the failure behavior of the system. The purpose of this paper is to develop a new approach for computing various performance measures, namely reliability, availability, MTBF (mean time between failures), ENOF (expected number of failures), failure rate and repair time, for any industrial system. In the proposed approach, the failure rates and repair times of all constituent components are obtained using genetic algorithms and then various performance measures are computed using fuzzy lambda–tau methodology. Washing system, the major part of paper industry is the subject of study. The interactions among the working components are modeled using Petri nets. Failure and repair rates are represented using triangular fuzzy numbers as they allow expert opinion, linguistic variables, operating conditions, uncertainty and imprecision in reliability information to be incorporated into system model. Based on calculated reliability parameters, a structured framework has been developed that may help the maintenance engineers to analyze and predict the system behavior.

1. Introduction

The complexity of an industrial system is growing day by day and so the job of system analysts has become more challenging, as they have to study, characterize, measure and analyze the uncertain systems' behavior, using various techniques, which require the component failure and repair pattern. But unfortunately, the data, available from the past record, are incomplete, imprecise, vague and conflicting, that leads to inadequate knowledge of basic failure events. Further, age, adverse operating conditions and the vagaries of the system, affect each unit of the system differently [1]. 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. For this purpose, the probabilistic and non-probabilistic techniques are used. The probabilistic approaches deal with uncertainty, which is random in nature, while the fuzzy approach deals with the uncertainty, which is due to imprecision associated with the complexity of the system as well as vagueness of human judgement [2]. Fuzzy methodology can deal with imprecise, uncertain dependent information related to system performance and provides a better, more consistent and mathematically more sound method for handling uncertainties in data than conventional methods, such

* Corresponding author. Tel./fax: +91 751 2449624.
E-mail addresses: ajay1dma@gmail.com, ajayfma@iittm.ac.in (A. Kumar).
URL: http://www.sites.google.com/site/ajay1dma/ (A. Kumar).

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as Bayesian statistics [3]. These approaches are still in developing phase and often use fuzzy sets, possibility theory and linguistic variables. The list includes, Singer [4] developed a new methodology to find out various reliability parameters using fuzzy set approach and fault tree. The failure rates and repair times were represented using triangular fuzzy numbers. Cheng and Mon [5] used interval of confidence for analyzing the fuzzy system reliability. Through theoretical analysis and computational results they have shown that their proposed approach is more general and straight-forward compared to that of Singer's. Chen [6] presented a new method for analyzing the fuzzy system reliability using fuzzy number arithmetic operations. Knezevic and Odoom [7] proposed a new methodology (fuzzy lambda–tau methodology) by making use of Petri nets (PNs) instead of fault tree. Fuzzy set theory was used to represent failure and repair data. The method is capable to provide the reliability indices more efficiently. Wang et al. [8] proposed a method to construct the failure number in the successive operating ranges using fuzzy paradigm. The method can easily model repairable and non-repairable cases, and identifies the system failed again after repair in the next time failure sequence data. The proposed methodology is demonstrated using different times of repairs for about 191 bus motors. Yadav et al. [9] presented a formal structure for capturing imprecise information and knowledge and utilizing it in reliability improvement estimation. A case example was presented to demonstrate the proposed approach. Jiang and Chen [10] established a basis for the reliability analysis of systems with fuzzy reliability. As an example, a case study about the fuzzy reliability analysis of a kind of sensor used in railway systems is provided to verify the logic of this algorithm. The computation results show that this algorithm fits the engineering experience. Tanrioven et al. [11] used fuzzy logic with Markov model to describe both transition rates and temperature-based seasonal variations, which identifies multiple weather conditions. The effectiveness of the methodology is shown by taking an example of power system. Zhao and Liu [12] investigated the expected system lifetime, system lifetime, and system reliability using fuzzy simulation and estimated the system performances. Some numerical experiments on multi-stage system and network system are provided. Huang et al. [13] proposed a new method using fuzzy arithmetics, artificial neural network and genetic algorithms to determine the membership function of the estimates of the parameters and the reliability function of multi-parameter lifetime distributions. The effectiveness of the proposed method is illustrated with normal and Weibull distributions. Rao et al. [14] presented a solution to test interval optimization problem with uncertain/imprecise parameters with fuzzy-genetic approach along with a case of application from a safety system of Indian pressurized heavy water reactor. Ke et al. [15] proposed a procedure to construct the membership functions of the system characteristics assuming times to failure and times to repair of the operating and standby units to follow fuzzified exponential distributions. The practicality of the proposed approach is illustrated by taking a numerical example. Wang and Watada [16] studied the redundancy allocation problems to a parallel-series system using fuzzy random variables. Some numerical examples are provided to illustrate the feasibility of the approach and quantify its effectiveness. Komal et al. [17] proposed a genetic algorithms based lambda–tau (GABLT) technique using traditional lambda–tau methodology and genetic algorithm. The approach is applied to press and washing system in a paper industry and gave recommendations to improve the system performance. Taheri and Zarei [18] investigated Bayesian system reliability in vague environments. The model parameters are assumed to be vague random variables with vague prior distributions and the vague Bayes estimate of system reliability has been calculated. Some examples have been shown to clarify the proposed approach. Kumar et al. [19] analyzed the reliability of waste clean-up manipulator using real coded genetic algorithms and fuzzy lambda–tau methodology. Various reliability parameters have been computed and sensitivity analysis has been done with various rate of occurrence of failure.

Apart from the reliability of repairable systems, fuzzy methodology is widely used for accessing human reliability and to find out the relative importance of human factors affecting human reliability [7,20]. Bertolini [21] analyzed human reliability and calculated the probability of erroneous actions using a fuzzy classification system. Li et al. [22] developed a new fuzzy human error risk assessment methodology for determining human error risk importance. The modeling is done using fuzzy logic and a case example is presented to demonstrate the proposed approach. Results show that the method is more realistic than the traditional ones, and it is practicable and valuable.

Among the inexact reasoning methods, fuzzy methodology (FM) acts as one of the most viable and effective tool. On the other hand genetic algorithm (GA), a member of heuristic techniques, is also a powerful tool and is used many times for reliability/availability optimization. GA performs better when the solution space to be searched, is relatively large, noisy and nonlinear. Hsieh et al. [23] utilized genetic algorithms and solved various reliability design problems, such as reliability optimization of series systems, series–parallel systems and complex systems. Jeang [24] suggested that computer aided simulation software would give the optimal design for reliability. Many methods have been developed and have been used for reliability design. However, a well-defined knowledge based method has not been found in the literature for reliability design and optimization. Considering maximum system reliability and minimal total cost, Li [25] solved the related problems by multiple fuzzy objective planning. Ramirez-Marquez and Coit [26] proposed a new heuristic approach for solving the redundancy allocation problem for multi-state series–parallel systems. Yalaoui and Chatelet [27] formulated an approximated function for the reliability allocation problem in a series–parallel system. You and Chen [28] proposed an efficient heuristic approach for series–parallel redundant reliability problems. Liu et al. [29] proposed a novel state selection technique for reliability evaluation of power systems. The fast sorting algorithm (FSA) has been derived to select quickly the required number of the system states in descending probability order with the minimum number of computations and comparisons. The system states can be dynamically selected and analyzed until the specified accuracy is satisfied. Juang et al. [30] proposed a new method to compute optimal values of MTBF and MTTR based on GA. A knowledge-based interactive decision support system was developed to assist the designers set up and to store component parameters during the intact design process of repairable series–parallel system. Azaron et al. [31] used a genetic algorithm approach to solve a