Expert Systems with Applications 41 (2014) 489–501

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

An approach for analyzing the reliability of industrial systems using soft-computing based technique

Harish Garg [a,*], Monica Rani [b], S.P. Sharma [b]

[a] School of Mathematics and Computer Applications, Thapar University Patiala, Patiala 147004, Punjab, India
[b] Department of Mathematics, Indian Institute of Technology Roorkee, Roorkee 247667, Uttarakhand, India

ARTICLE INFO

Keywords:
ABCBLT
Fuzzy reliability
Artificial bee colony
Lambda–Tau methodology
Membership function
Repairable industrial system

ABSTRACT

The purpose of this paper is to present a novel technique for analyzing the behavior of an industrial system by utilizing vague, imprecise, and uncertain data. In this, two important tools namely traditional Lambda–Tau and artificial bee colony algorithm have been used to build a technique named as an artificial bee colony (ABC) algorithm based Lambda–Tau (ABCBLT). In real-life situation, data collected from various resources contains a large amount of uncertainties due to human errors and hence it is not easy to analyze the behavior of such system up to a desired accuracy. If somehow behavior of these systems has been calculated, then they have a high range of uncertainty. For handling this situation, a fuzzy set theory has been used in the analysis and an artificial bee colony has been used for determining their corresponding membership functions. To strengthen the analysis, various reliability parameters, which affects the system performance directly, have been computed in the form of fuzzy membership functions. Sensitivity as well as performance analysis has also been analyzed and their computed results are compared with the existing techniques result. The butter–oil processing plant, a complex repairable industrial system has been taken to demonstrate the approach.

1. Introduction

Over the last couple of decades, globalization and other factors have significantly changed the business environment. In today's competitive industrial market, firms are facing significant ongoing challenges. Although, the concept of failure analysis is nearly an unavoidable phenomenon for all repairable industrial systems. The cause of failure may be deteriorating and/or human error. With the advances in technology and growing complexity of systems and insistence on product quality, the importance of reliability and maintainability in industries has increased attention and hence job of reliability/system analysts more challenging. In order to maintain the reliability of sophisticated systems to a higher level, the systems' optimum structural design or highly reliable components of these systems are required, rather both of them may be sought simultaneously. Since, system structure is virtually designed under the limitations such as weight, volume, cost etc. So the system reliability cannot be further improved effectively by considering these constraints. Replacement of lesser reliable components with highly reliable components can improve the system reliability but the cost constraint may violate. Therefore, it is very difficult to construct an accurate and complete mathematical model of an industrial system which may be very close to the real situation. Moreover, traditional analytical techniques (mathematical and statistical models) need large amounts of data, which are difficult to obtain because of constraints (i.e., rare events of components, human errors and economic considerations) for estimation of the failure/repair characteristics of the system. Even if the data are available (collected from various historical or available resources), they are often inaccurate and are thus subject to uncertainty, i.e. historical records can only represent the past behavior but may be unable to predict the future behavior of the equipment. Thus, it may be difficult or even impossible by using conventional reliability analysis methods to establish a rational database to accommodate all operating and environmental conditions. Further, age and adverse operating conditions add to the vagaries of the system and affect each unit of the system differently. Fuzzy methodology, defined by Zadeh (1965) is an alternative to this problem since it 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 Bayesian statistics, Markov process, etc. In reliability and maintainability studies a small number of researchers have addressed the issue of handling uncertainties particularly related to failure data. For instance, Singer (1990)

* Corresponding author. Tel.: +91 8699031147.
E-mail addresses: harishg58iitr@gmail.com (H. Garg), monicaiitr@gmail.com (M. Rani).
URLs: http://site.google.com/sites/harishg58iitr/ (H. Garg), http://site.google.com/sites/monicaiitr/ (M. Rani).

0957-4174/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2013.07.075

proposed a new approach to overcome the shortcoming of conventional fault tree in reliability analysis. The relative frequencies of the basic events are considered as fuzzy numbers. Cheng and Mon (1993) used confidence interval for analyzing the fuzzy system reliability. Through theoretical analysis and computational results, it was shown that their proposed approach was more general and straightforward compared to Singer's. Chen (1994) presented a new method for analyzing system reliability using fuzzy number arithmetic operations. 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 (Cai, 1996; Chen, 1996; Mon & Cheng, 1994; Knezevic & Odoom, 2001; Sharma & Garg, 2011; Zadeh, 1965; Ross, 2004; Zimmermann, 2001).

As above researchers have analyzed the reliability or availability index alone of the industrial system which does not give any deeper idea about the complete behavior of the system because a lot of factors exist which overall influence the systems' performance and consequently their behavior. Therefore, some other reliability indices must be included in the analysis which may help the management to understand the effect of increasing/decreasing the failure and repair rates of a particular component upon the overall performance of the system. In that direction, Knezevic and Odoom (2001) and Garg (2013) approaches may be used in which they had analyzed the behavior of the system in terms of various reliability parameters such as system failure rate, repair time, mean time between failures (MTBF), expected number of failures (ENOF), reliability and availability by quantified the uncertainties with the help of fuzzy and vague set theory. The expression of these reliability indices is given in Table 1. Triangular fuzzy numbers (TFNs) have been used in their analysis for handling the uncertainties in the data. Based on these approaches the reliability analysis of some process industrial systems has been analyzed by the researchers in form of fuzzy membership functions (Komal, Sharma, & Kumar, 2009; Sharma & Garg, 2011; Sharma & Rani, 2012).

But it has been analyzed from the literature that when this approach has been applied in a large or complex structured system then the computed reliability indices have a wide range of uncertainties in the form of spread (support). This is because of the various fuzzy arithmetic operations used in the computations (Cheng & Mon, 1993; Mon & Cheng, 1994; Garg, Sharma, & Rani, 2012b; Garg & Sharma, 2012). This means the computed indices have a high range of uncertainty, thus cannot give the precise idea about the behavior of the system. In other words, the computed results do not follow the real trend of the system and will not give an exact idea about the behavior analysis of the system. In order to take more appropriate actions to improve the performance of the system and to reduce the uncertainty level, it is necessary that the spread of each reliability index must be reduced up to a desired degree of accuracy so that plant personnel may use these indices to analyze the behavior of the system more closely. Mon and Cheng (1994) suggested a computational method to evaluate the fuzzy reliability of a non-repairable system by formulating a nonlinear optimization problem and solved by using "GINO" a software package. But during last few decades, variety of methods and algorithms exists for optimization and hence applied in different environment which includes genetic algorithm (GA) (Goldberg, 1989; Ravi, Reddy, & Zimmermann, 2000; Komal et al., 2009), particle swarm optimization (PSO) (Kennedy & Eberhart, 1995; Eberhart & Kennedy, 1995; Garg & Sharma, 2012), artificial bee colony (ABC) (Basturk & Karaboga, 2006; Karaboga & Akay, 2009; Karaboga & Ozturk, 2011) etc. ABC is one of the most recently defined algorithms by Karaboga (2005), motivated by the intelligent behavior of honey bees and have been widely used to solve such types of optimization problems.

As compared with other meta-heuristics ABC does not employ crossover operators to produce new or candidate solutions from the present ones. It produces the candidate solution from its parent by a simple operation based on taking the difference of randomly determined parts of the parent and a randomly chosen solution from the population. Moreover, ABC employs the least number of control parameters than others as it employs only population size (colony size) and a maximum cycle number. Due to these features and have the advantages of memory, multi-character, local search and solution improvement mechanism, ABC is able to discover an excellent optimal solution. Yeh and Hsieh (2011) and Hsieh and Yeh (2012) shows that the solution of series–parallel problem found by ABC is better than the other meta-heuristic techniques. Garg et al. (2012b) and Garg, Rani, and Sharma (2012a) have used ABC algorithm for determining the membership functions of the reliability problems by considering the time varying failure rate and constant repair rate model of an industrial system. Motivated by this, the main emphasis of the present study is to present a novel technique named as an artificial bee colony based Lambda–Tau (ABCBLT) for analyzing the behavior of the complex repairable industrial system up to a desired degree of accuracy by utilizing uncertain and limited data. With this technique, expression of the various reliability parameters is obtained from Lambda–Tau technique and their corresponding membership functions are obtained after solving a nonlinear programming problem. An ordinary arithmetic operation has been used in the analysis instead of fuzzy arithmetic operations. The technique has been demonstrated through a case study of butter–oil processing plant and their results are compared with the existing fuzzy Lambda–Tau (FLT) and genetic algorithm based Lambda–Tau (GABLT) techniques. Sensitivity as well as performance analysis on the system availability has also been addressed. The obtained results may help the system analyst for reallocating the resources to achieve the targeted goal of higher profit.

The rest of the manuscript is described as follows: Section 2 discusses the basic concepts of the fuzzy set theory that have used during the analysis. In Section 3, description of the proposed technique ABCBLT has been given. The description of butter-oil processing plant is given in Section 4. The computation results and their discussion are carried out in Section 5 along with their behavior, sensitivity and performance analysis. Finally, some concrete conclusions have been presented in Section 6.

Table 1
Some reliability parameters.

Parameters	Expressions
Failure rate	$\text{MTTF}_s = \frac{1}{\lambda_s}$
Repair time	$\text{MTTR}_s = \frac{1}{\mu_s} = \tau_s$
Mean time between failures	$\text{MTBF}_s = \text{MTTF}_s + \text{MTTR}_s$
Reliability	$\text{R}_s = e^{-\lambda_s t}$
Availability	$\text{A}_s = \frac{\mu_s}{\lambda_s+\mu_s} + \frac{\lambda_s}{\lambda_s+\mu_s} e^{-(\lambda_s+\mu_s)t}$
Expected numbers of failures	$\text{W}_s(0,t) = \frac{\lambda_s \mu_s t}{\lambda_s+\mu_s} + \frac{\lambda_s^2}{(\lambda_s+\mu_s)^2}[1 - e^{-(\lambda_s+\mu_s)t}]$

2. Basic concepts of fuzzy set theory

The section presents only those basic concepts related to fuzzy set theory, which are helpful for analyzing system behavior.

2.1. Fuzzy set

The concept of fuzzy set was introduced by Zadeh (1965), which can be defined on the universe of discourse U as $\widetilde{A} = \{< x, \mu_{\widetilde{A}}(x) > | x \in U\}$, where $\mu_{\widetilde{A}}$ is the membership function of the fuzzy set $\widetilde{A}$ defined as $\mu_{\widetilde{A}} : U \to [0,1]$ and $\mu_{\widetilde{A}}(x)$ indicates the degree of membership of x in $\widetilde{A}$ and its value lies between zero