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Entropy based region reducing genetic algorithm for reliability redundancy allocation in interval environment

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ABSTRACT

This research paper presents a multi-objective reliability redundancy allocation problem for optimum system reliability and system cost with limitation on entropy of the system which is very essential for effective sustainability. Both crisp and interval-valued system parameters are considered for better realization of the model in more realistic sense. We propose that the system cost of the redundancy allocation problem depends on reliability of the components. A subpopulation and entropy based region reducing genetic algorithm (GA) with Laplace crossover and power mutation is proposed to determine the optimum number of redundant components at each stage of the system. The approach is demonstrated through the case study of a break lining manufacturing plant. A comprehensive study is conducted for comparing the performance of the proposed GA with the single-population based standard GA by evaluating the optimum system reliability and system cost with the optimum number of redundant components. Set of numerical examples are provided to illustrate the effectiveness of the redundancy allocation model based on the proposed optimization technique. We present a brief discussion on change of the system using graphical phenomenon due to the changes of parameters of the system. Comparative performance studies of the proposed GA with the standard GA demonstrate that the proposed GA is promising to solve the reliability redundancy optimization problem providing better optimum system reliability.

1. Introduction

In general, reliability redundancy allocation means that the system design have redundant components in series–parallel, parallel-series or parallel systems. Also, these alternative designs achieve the goal of optimal system reliability by optimal allocation of redundant components. Reliability of a multi-stage system can be improved by adding similar components as redundancy to each subsystem, also may be some different components which can be considered as design alternatives in a subsystem. Therefore, redundancy allocation problem is to improve reliability of a system such that the limited available resources are utilized efficiently.

The concept of entropy for redundancy allocation is indispensable for system safety since existing components are often affected by several undesirable causes, lead to represent external and internal threats that collapse the system until it no longer can sustain the system. In this paper, we challenge this form of whole entropy by adding inputs as redundant components to the system, whereas individual continues to exist through spontaneous changes in the inputs and composition of the system. Thus, the system entropy plays a vital role in formulation of the redundancy allocation problem. Cost of component of a particular stage may not be same in spit of same purpose (stage) since it depends on manufacturer needs. Keeping in mind of that fact, we consider reliability depended cost of component in this work.

In this paper, we propose a multi-objective reliability redundancy allocation problem to find the optimum number of redundant components, which maximize the system reliability and minimize the system cost with entropy as constraint for the system stability. We propose the component reliability dependent system cost for the redundancy allocation problem. We consider fixed and interval-valued parameters of the model to make the system more practical and flexible. We use symmetrical form of interval numbers by interval valued parametric functional form Mahapatra and Mandal (2012). We propose a subpopulation and entropy based region reducing GA with Laplace crossover and

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power mutation operations to analyze the reliability optimization problem by evaluating the optimum number of redundant components at each stage of the system. The procedure is illustrated by the case study of a break lining manufacturing plant. Pareto optimal solution is presented using the proposed GA approach in crisp and interval valued parameters for the redundancy allocation based system reliability optimization problem. We compare the performance of the proposed GA with the single-population based normal GA by evaluating the optimum system reliability and system cost with the optimum number of redundant components at each stage of the system. A set of theoretical discussion with numerical examples is provided to show the concept of the proposed optimization technique. We also discuss about the change of the system due to the changes of parameters of the system using graphical phenomenon.

The rest of the paper is organized as follows: In Section 2, we discuss the related work on the topic of the redundancy allocation problem for system reliability with/without system entropy. In Section 3, we present the interval number and formulation of the reliability redundancy allocation model in fixed and interval environment. Section 4 describes the GA based constraint handling and multi-objective optimization approaches. In Section 5, the proposed GA developed for the reliability redundancy allocation problem is discussed in detail. An illustrative example of reliability redundancy model has been described in Section 6 from the case study of a break lining manufacturing plant. Numerical and graphical exposure based on the proposed reliability redundancy allocation model with crisp and interval-valued model parameters are presented in Section 7. Some conclusions are drawn in Section 8.

2. Related work

Kuo, Prasad, Tillman, and Hwang (2001) illustrated the allocation of redundant components in a system to increase the system reliability, which is important in reliability engineering. Hsieh (2002) investigated the series parallel redundant reliability problems with multiple component choices by linear approximation. Zhao and Liu (2003) illustrated parallel redundant and standby redundant system by stochastic programming. Charles, Chu, Adjallah, and Yalaoui (2003) considered the allocation of redundancy to each subsystem of parallel-series system for target reliability with minimizing the system cost. Xie, Dai, and Poh (2004) demonstrated the allocation of redundant component to increase system reliability. Yum and Kim (2004) presented multi-level redundancy optimization in series system by a mixed integer programming, a GA and a heuristic algorithm. Cheng (2007) presented a hybrid GA method consisting of artificial neural network for structural reliability analysis. Chen and Chiang (2008) proposed a novel hybrid approach combining a multi-objective GA and a neural network for multi-objective optimization of a reliability system. Mahapatra and Roy (2011) presented GA approach for system reliability of bridge network in fuzzy environment. Wang, Yeo, Buyyac, and Su (2011) proposed a look-ahead GA to intelligently optimize the makespan and reliability of a workflow application. Sahoo, Bhunia, and Kapur (2012) solved the constrained multi-objective reliability optimization problem with interval valued reliability of each component by maximizing the system reliability and minimizing the system cost using GA. Safari (2012) proposed a variant of the non-dominated sorting GA to solve a novel mathematical model for multi-objective redundancy allocation problems. Recently, several researchers proposed different kinds of heuristics to solve various types of reliability redundancy allocation problems (Deco, Frangopol, & Zhu, 2012; He, Wu, Xu, Wen, & Jiang, 2013; Sadjadi & Soltani, 2012; Soltani, Sadjadi, & Tofighb, 2013; Zhao, Chan, Li, & Ng, 2013).

In recent years, entropy has been employed to analyze reliability and importance measures. Rocchi (2002) introduced the entropy function in order to study the reliability and reparability of systems. Ridder (2005) investigated the application and usability of the cross-entropy method for rare event simulation in Markovian reliability models. Kroese, Kin, and Nariai (2007) introduced an approach based on cross-entropy method for optimization of network reliability. For series–parallel reliability redundancy allocation problem, entropy represents the lack of the information about the state of the each subsystem. Mahapatra and Mahapatra (2011) used intuitionistic fuzzy optimization technique on reliability redundancy optimization with entropy function. Tang, Lu, Jiang, Pan, and Zhang (2013) proposed a novel entropy-based importance measure for random variables to identify the important variables of a system subjected to many random variables. He and Qu (2009) proposed a new important measure of fault tree analysis based on possibilistic information entropy. Tang, Lu, Pan, and Zhang (2013) proposed a novel entropy-based importance measure to identify the effect of the uncertain variables on the system, which is subjected to the combination of random variables and fuzzy variables. Jung, Chin, and Cardoso (2011) proposed an entropy-based process measure to quantify the uncertainty of business process models. Tang, Lu, Feng, and Wang (2013) proposed an efficient importance sampling method based on the cross-entropy method to perform reliability analysis for the inside flap of an aircraft.

3. Reliability redundancy allocation model

Notation:
Reliability redundancy allocation model is developed using the following notation:

R_i	Reliability of each component in ith stage,
$\widehat{R}_i$	Interval-valued component reliability of each component in ith stage,
C_i	Cost of each component in ith stage,
$\widehat{C}_i$	Interval-valued component cost of each component in ith stage,
x_i	Number of redundant components in ith stage (decision variables),
a_i	Shape parameter of each component in ith stage,
α_i	Half width of the component reliability interval in ith stage,
β_i	Half width of the component cost interval in ith stage,
γ	Half width of the system entropy interval,
$R_s(x_1, x_2, \ldots, x_n)$	System reliability function of the reliability model,
$C_s(x_1, x_2, \ldots, x_n)$	System cost function of the reliability model,
$E_s(x_1, x_2, \ldots, x_n)$	Maximum entropy of the reliability model,
$\widehat{E}_s(x_1, x_2, \ldots, x_n)$	Interval-valued system entropy.

3.1. Symmetrical parametric form of interval number

Interval numbers are subset and generalization concept of the set of real numbers $\mathbb{R}$.

Definition 1. *Interval number:* An interval number is a set containing a closed interval of real numbers and it is denoted by $A = [a_L, a_U] = \{x : a_L \leqslant x \leqslant a_U, x \in \mathbb{R}\}$ where a_L and a_U are the lower and upper bounds of the interval number respectively.

Definition 2. *Interval-valued function (Symmetrical form):* An interval $[a_L, a_U]$, where $a_L > 0$, can be expressed in symmetrical form as $[c_1 - \alpha, c_1 + \alpha]$ where $c_1 = \frac{a_L + a_U}{2}$ and $\alpha = c_1 - a_L = a_U - c_1$. Here, c_1