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Reliability-redundancy Optimization Problem with Interval Valued Reliabilities of Components via Genetic Algorithm

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Abstract. This paper deals with the reliability-redundancy optimization problem considering the reliability of each component as an interval valued number that involves the selection of components with multiple choices and redundancy levels which maximize the overall system reliability subject to the given resource constraints arise on cost, volume and weight. Most of the classical mathematical methods have failed in solving the reliability-redundancy optimization problems because the objective functions as well as constraints are non-convex in nature. As an alternative to the classical mathematical methods, heuristic methods have been given much more attention by the researchers due to their easier applicability and ability to find the global optimal solutions. One of these heuristics is genetic algorithm (GA). GA is a computerized stochastic search method of global optimization based on evolutionary theory of Darwin: "The survival of the fittest" and natural genetics. Here we present GA based approach for solving interval valued mixed integer programming in reliability-redundancy optimization problem with advanced genetic operators. Finally, a numerical example has been solved and also to study the effects of changes of different GA parameters, sensitivity analyses have been carried out graphically.

Keywords: Reliability-redundancy optimization, Genetic algorithm, Mixed-integer programming, Interval mathematics, Interval order relations

1. Introduction

Development of the design of high-tech system depends on the selection of components and configurations to meet the functional requirements as well as performance specification. Measures of system performance are basically of four types: (i) reliability (ii) availability (iii) mean time to failure and (iv) percentile life. Reliability has been widely used and studied as the primary performance measure for non maintained systems and becomes an important concern now-a-days, because due to increase of complexity, sophistication and automation of high-tech systems, system reliability tends to decrease. In 1952, the Advisory group on the reliability of electronic equipment defined the reliability in a wider sense: reliability indicates the probability implementing specific performance or function of products and achieving successfully the objectives within a time schedule under a certain environment. For a system with known cost, reliability, weight, volume and other system parameters, the corresponding design problem becomes a combinatorial optimization problem. The most well known reliability design problems of this type are referred to as the reliability-redundancy optimization problems.

This type of problem is generally a nonlinear mixed-integer programming problem. To enhance the component reliability and providing redundancy while considering the tradeoff between the system performance and resources, optimal reliability design that aims to determine an optimal system-level configuration has long been a hot topic in reliability engineering design. Over the last four decades, a number of notable works has been done in this topic based on various system configurations, performance measures, optimization techniques and other features for the improvement of system reliability. Among these, one may refer to the recent works of Kuo and Prasad (2000), Kuo and Wan (2007), Zhao et al. (2007), Liang and

Smith (2004), Onishi and Kimura (2007), Aggarwal and Gupta (2005), Ha and Kuo (2006a, 2006b), Gen and Yun (2006), Coelho (2009), Sung and Cho (1999), Coit, Jin and Wattanapongsakorn (2004), Zafiropoulos and Dialynas (2004), Ramirez-Marquez, Coit and Kanok (2004), Ramirez-Marquez and Coit (2007), Cui et al. (2004), Painton and Campbell (1995), Utkin an Gurov (1999, 2001), Marseguerra and Podofillini (2005), Ravi and Reddy (2000), Kuo et al. (2001), Sun and Li Duan (2002) and Sun, Mckinnon and Li (2001). In their works, the reliabilities of the system components are assumed to be known and fixed positive number which lies between zero and one. However, in real life situations, the reliability of an individual component may not be fixed. It may fluctuate due to different reasons. It is not always possible for a technology to produce different components with exactly identical reliabilities. Moreover, the human factor, improper storage facilities and other environmental factors may affect the reliabilities of the individual components. So, the reliability of each component is sensible and it may be treated as a positive imprecise number. To tackle the problem with such imprecise numbers, generally stochastic, fuzzy and fuzzy- stochastic approaches are applied and the corresponding problems are converted to deterministic problems for solving them. In stochastic approach, the parameters are assumed to be random variables with known probability distributions. In fuzzy approach, the parameters, constraints and goals are considered as fuzzy sets with known membership functions or fuzzy numbers. On the other hand, in fuzzy-stochastic approach, some parameters are viewed as fuzzy sets/fuzzy numbers and others as random variables. However, it is a formidable task for a decision maker to specify the appropriate membership function for fuzzy approach and probability distribution for stochastic approach and both for fuzzy -stochastic approach. So, to avoid these difficulties for handling the imprecise numbers by different approaches, one may use interval number to represent the imprecise number, as this representation is the most significant representation among others. Due to this representation, the system reliability would be interval valued. To the best of our knowledge, only a very few researchers (Gupta (2009), Bhunia (2010) and Sahoo (2010, 2012)) have done their works considering interval valued reliabilities of components,

In this study, we have considered GA-based approach for solving mixed-integer reliability redundancy optimization problem considering the reliability of each component as interval valued. As the objective function of the redundancy allocation problem is interval valued, to solve this type of problem by GA, order relations for intervals numbers are essential. Over the last three decades, very few researchers proposed the order relations of interval numbers in different ways. Recently, Mahato and Bhunia [28] proposed the modified definitions of order relations with respect to optimistic and pessimistic decision maker's point of view for maximization and minimization problems separately. Very recently, Sahoo, Bhunia and Roy (2011) proposed the simplified definition of interval order relations ignoring optimistic and pessimistic decisions. However, it has been observed that both the definitions give the same result.

In this paper, we have considered the problem of reliability-redundancy optimization considering the reliability of each component as an interval valued number that maximizes the overall system reliability subject to the given resource constraints arise on cost, volume and weight. The corresponding problem has been formulated as non-linear mixed integer constrained optimization problem with interval objective and some of the variables (i.e., reliability of each component) are interval valued. For solving this problem, we have developed advanced genetic algorithm with interval valued fitness function and Big-M penalty technique. To illustrate the method, a numerical example has been solved. Finally, to test the performance of the developed method, sensitivity analyses have been performed graphically with respect to different GA parameters.

2. Nomenclature

n	number of subsystems
$x = (x_1, x_2, ..., x_n)$	vector of the redundancy allocation for the system