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Robust counterpart optimization for the redundancy allocation problem in series-parallel systems with component mixing under uncertainty

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ABSTRACT

In this paper, a robust optimization approach is used to solve the redundancy allocation problem (RAP) in series-parallel systems with component mixing where uncertainty exists in components' reliabilities. In real world, the reliabilities of components are imprecisely estimated or the reliability of some components may vary due to some realistic factors. Therefore, we may deal with a system where there are many components with uncertain values of reliabilities. To deal with this problem, for the first time a robust optimization approach is applied to RAP with component mixing to produce a robust solution, which is relatively insensitive with respect to uncertainty in reliability of components. In addition, the advantages of the proposed robust technique are illustrated by considering a series-parallel system and finding the suitable redundancy levels and then Monte Carlo simulation is implemented to examine the quality of the robust solutions. The results indicate that applying the proposed robust RAP can be more reliable to determine system reliability in the designing phase of systems.

1. Introduction

To survive in competitive markets, it is important to present highly reliable systems or products as far as the available resources allow. Therefore, during the designing stage, this requirement should be ensured, through reliability optimization methods. Soltani [1] presented a comprehensive review on reliability optimization problems considering both deterministic and non-deterministic problems. The RAP, a well-known reliability optimization problem, involves the simultaneous selection of elements and a system-level design configuration, which can collectively meet all design constraints in order to optimize some objective functions, such as system reliability and/or total system cost. In this problem, there are several types of elements with different levels of cost, reliability, weight, and other characteristics. The RAP is essential for designing any kind of high-tech complicated systems with many elements and various stringent reliability requirements such as electrical power systems, transportation systems, safety systems, telecommunication and satellite systems, etc. For more study on redundancy allocation problems readers are also referred to references [2–12,42,43].

In reality, the reliability of systems may not be constant and may vary due to some factors such as improper storage conditions, using manner, temperature, pressure, humidity, etc. To tackle such uncertainty, there are some approaches such as stochastic

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programming, fuzzy programming, interval programming, regret-based methods and robust counterpart optimization. Studies of system reliability by considering the components' reliabilities as imprecise were initiated by some researchers such as Coolen and Newby [13] who considered Bayesian reliability analysis. Recently, Benkamra et al. [41] considered the problem of estimating the reliability of a series- parallel system, where the components reliabilities are independent Bernoulli random variables with beta priors on their parameters and which are, themselves, independent.

In the stochastic programming framework, the estimation of reliability is considered as a random variable with a given distribution. A common approach to cope with difficult stochastic programming problems is to maximize the expected value. Rubinstein et al. [14] maximized the expected values of the random system reliability and used a Genetic Algorithm (GA) to solve the Redundancy Allocation Problem (RAP) with uncertain component properties. However, the maximization of the expected value is not appropriate for decision makers who are risk-averse. Therefore, it is useful to consider the problem as multiple objectives of maximizing the system reliability estimate and minimizing the variance of that estimate. Marseguerra et al. [15] considered reliability optimization of a network system with stochastic components' reliabilities which are generated by Monte Carlo simulation. They found the optimal redundancy level through maximizing network reliability estimate and minimizing its associated variance. Coit and Smith [16] considered uncertainty with specified mean and standard deviation of components' reliabilities. Reddy et al. [17] considered a series-parallel system with stochastic components' reliabilities. They used simulation method to generate feasible configurations and select the best configuration from reliability standpoint. Tekiner and Coit [18] considered the problem of minimizing the coefficient of variation of the system reliability estimate and presented two algorithms to deal with it. Zhao and Liu [19] developed a stochastic programming technique for RAP.

In the field of fuzzy programming, some researchers applied the fuzzy set theory to reliability analysis. Park [20] used fuzzy in the reliability apportionment problem for a two-component series system subject to a single constraint and solved it by fuzzy non-linear programming technique. Mahapatra and Roy [40] used a fuzzy multi-objective optimization method for optimization of a series and complex system reliability. Mahapatra and Mahapatra [21] considered the problem of minimizing system cost of a series system with the target of system reliability in fuzzy environment and formulated the reliability model as a fuzzy parametric geometric programming problem. Recently, Soltani and Sadjadi [22] presented a robust possibilitic programming approach and developed robust models for RAP with active strategy.

In the area of interval programming as a non-probabilistic way to treat uncertainty, Sahoo et al. [23] considered a multi-objective reliability optimization problem by maximizing the system reliability and minimizing the system cost in a system with interval valued reliability of components, and formulated four different problems using interval mathematics. They solved these problems by applying GA and the concept of Pareto optimality. Taguchi et al. [24] considered the reliability optimization problem as a nonlinear programming with interval coefficients in the objective and solved the resulted problem by GA. Taguchi et al. [25] transformed an optimal design of system reliability problem with interval coefficients into the single objective nonlinear integer programming problem without interval coefficients and solved it by an improved GA. Bhunia et al. [26] considered a reliability optimization problem in an n-stage series system with interval valued reliabilities and stochastic resource constraint with known probability distributions such as uniform, normal and log normal distributions. After converting the problem into its equivalent deterministic form, they employed the GA method to solve the problem. Gupta et al. [27] considered RAP for series system with interval valued reliabilities of components and solved it by the GA based penalty function technique. Tang et al. [28] used partial order relations and interval operations. In their approach, an interval optimization problem of system reliability is transformed into a single objective linear programming problem without interval coefficients. Sahoo et al. [29] developed a GA to solve reliability-redundancy optimization problem of series-parallel/parallel-series/complex system with interval valued reliabilities of components. Cheng [30] considered the uncertain parameters of mechanical components as non-probabilistic interval variables. They formulated the optimal design as a two-level optimization problem. More recently, Soltani et al. [31] presented an interval programming approach for RAP with the choice of a redundancy strategy.

Regarding regret-based methods, Feizollahi and Modarres [32], Soltani et al. [33] and Sadjadi and Soltani [44] considered series-parallel systems with respectively active, cold standby and a choice of redundancy strategies considering interval uncertainty for reliability of components and used the Min-Max regret criterion as a robustness measure to deal with interval uncertainty.

In the interval approach, uncertainties are characterized by crisp sets and the system's reliability is usually evaluated based on the lower and upper bounds of the low-level's reliability. In the stochastic programming approach, the uncertain parameters are viewed as random variables with known probability distributions. In the fuzzy programming approach, the uncertain parameters are viewed as fuzzy numbers or fuzzy sets with known membership functions. However, in real-world, it is not easy for decision makers to specify either probability distributions or membership functions or both. In many practical situations, the probability distribution function of components' lifetimes may be unknown or partially known. In fact, there are not sufficient statistical data in most of the cases where the system is newly designed or manufactured. Therefore, only some partial information about the components is known. In addition, in most cases the upper and lower bounds of intervals are not known exactly.

An approach to tackle these difficulties is to consider an uncertainty set for the uncertain parameters. In this case, the robust counterpart optimization is an approach for modeling uncertainty in data in which the uncertain parameters are assumed to take arbitrary values in a prescribed closed uncertainty set such as ellipsoid, ball, polyhedral, box, or their intersections. This technique generally refers to the modeling of optimization problems with data uncertainty to obtain a solution which is guaranteed to be good for all or most possible realizations of the uncertain parameters. Soyster [34] is the first who introduced the idea of robust optimization within the concept of uncertainty set. His proposed robust formulation, results in a high protection while being more conservative in practice. Bertsimas and Sim [35] defined a family of polyhedral uncertainty sets that encode a budget of