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Genetic Algorithm Approach to Solve Integer Nonlinear Programming Problem in Reliability Optimization

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Abstract. In the recent years, different types of optimization techniques have been advanced rapidly and applied widely to solve several optimization problems. These advancements are depends on both the upgrading progress of modern computer technologies and that of optimization process for large scale system. The most important optimization problem in reliability optimization is redundancy allocation problem. However, these problems have always been solved in the precise setup. In this paper, the reliability of each component is considered to be imprecise. The goal of this paper is to solve the redundancy allocation problem that maximize the overall system reliability subject to the given resource constraints. This impreciseness has been represented by interval number. This type of problem has been formulated as an interval valued constrained optimization problem. Then the constrained optimization problem has been transformed into unconstrained one by penalty function technique then solved by Genetic Algorithm. Finally, to illustrate the methodology, a numerical example has been presented and solved for illustration purpose.

Keywords: Reliability Optimization, Redundancy allocation problem, Genetic algorithm, System reliability, Penalty function technique.

1. Introduction

Reliability optimization has become an important issue in recent years because modern high-tech industrial processes with increasing levels of sophistication comprise most engineering systems today. Since last few decades, many publications have addressed this problem using different system structures, performance measures, optimization techniques and options for reliability improvement. The subject “Reliability Optimization” appeared in the literature in due late 1940s and was first applied to communication and transportation systems. One of the goals of the reliability engineer is to find the best way to increase the system reliability. As systems are becoming more complex, the consequences of their unreliable behavior have become severe in terms of cost, effort and so on. For a system with known cost, reliability, weight, volume and other parameters, the corresponding design problem is known as combinatorial optimization problem. The well known reliability design problem is referred to as redundancy allocation problem. The objective of this problem is to determine the number of redundant components that maximize the system reliability or minimize the system cost under the several resource/budget constraints. As redundancy allocation problem is a nonlinear integer programming problem, it cannot be solved by direct/indirect or mixed search methods due to discrete search space. According to Chern [1], redundancy allocation problem is NP-hard. In the existing literature, it is observed that several methods, viz. heuristic methods [2-4], branch and bound method [5], reduced gradient method [6], integer programming method [7] etc. were used to solve such redundancy allocation problem. However, these methods have some advantages as well as disadvantages also. Therefore, with the development of genetic algorithm and other evolutionary algorithms, most of the researchers are motivated to use these methods in solving redundancy allocation problem as these methods provide more flexibility, require fewer assumptions on the objective as well as constraints.

However, in almost all the approaches mentioned earlier, the parameters of redundancy allocation problem have usually been taken to be precise values. However, in reality, the reliability of each component is imprecise due to human errors, improper storage facilities and other unexpected factors relating to environment. 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 this paper, we prefer to consider interval number because the problem under the three approaches can be converted into a problem in interval representation. Due to this new representation, the objective function of the reduced redundancy allocation problem is interval valued, which is to be maximized under given constraint. In the recent years, a number of works has been reported in the literature considering the parameters of the problem as interval valued. In this paper, we have considered redundancy allocation problem of series system with four subsystems. Each subsystem is connected in parallel with identical components. The reliability of each component is considered to be interval number. Then the corresponding problem has been formulated as an interval valued constrained optimization problem. Then the constrained optimization problem has been transformed into unconstrained one by Big-M penalty function technique then solved by Genetic Algorithm and Interval order relations developed by Sahoo et al. [8]. Finally, to illustrate the methodology, a numerical example has been solved and the computed results have been presented.

2. Assumptions and Notations

A redundancy allocation problem is formulated under the following assumptions and notations.

2.1. Assumptions:

(i) Reliability of each component is imprecise and interval valued.
(ii) Failures of components are mutually statistically independent.
(iii) The components as well as the system have two different states, viz. operating state and failure state.

2.2. Notations:

n	the number of subsystems
x	$(x_1, x_2, ..., x_n)$
x_j	the number of components in *j*-th subsystem, arranged in parallel
r_j	The reliability j-th *Component*
R_s	The system reliability
$r_j = [r_{jL}, r_{jR}]$	Interval valued reliability of *j*-th component
$[R_{SL}, R_{SR}]$	Interval valued system reliability
l_j, u_j	lower and upper bounds of x_j
g_i	The $i-th$ constraint function
b_i	The upper limit on the $i-th$ resource
$U(.)$	Uniform distribution
Ω	Feasible region
FS	Feasible Solution
NFS	Nonfeasible Solution

3. Mathematical formulation of the Problem

Let us consider a redundancy allocation problem of series system. Each subsystem is connected in parallel with identical components. Our objective is to maximize the overall system reliability subject to the given resource constraints. This can be done by finding the number of redundant components in each subsystem.

The general form of the redundancy allocation problem is as follows:

$$\text{Maximize } R_S = \prod_{j=1}^{n} \left[1 - \left(1 - r_j\right)^{x_j}\right] \quad (1)$$

$$\text{subject to } \; g_i(x) \le b_i, \; i = 1, 2, \cdots, m$$

where $1 \le l_j \le x_j \le u_j$, x_j is integer, $j = 1, ..., n$, b_i is the *i*-th available resource, $i = 1, 2, \cdots, m$.