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A new model for the redundancy allocation problem with component mixing and mixed redundancy strategy

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ABSTRACT

This paper develops a new model for redundancy allocation problem. In this paper, like many recent papers, the choice of the redundancy strategy is considered as a decision variable. But, in our model each subsystem can exploit both active and cold-standby strategies simultaneously. Moreover, the model allows for component mixing such that components of different types may be used in each subsystem. The problem, therefore, boils down to determining the types of components, redundancy levels, and number of active and cold-standby units of each type for each subsystem to maximize system reliability by considering such constraints as available budget, weight, and space. Since RAP belongs to the NP-hard class of optimization problems, a genetic algorithm (GA) is developed for solving the problem. Finally, the performance of the proposed algorithm is evaluated by applying it to a well-known test problem from the literature with relatively satisfactory results.

1. Introduction

Recent years have witnessed a growing interest in reliability optimization as an important subfield in reliability engineering. Redundancy allocation is one of the most important approaches employed to enhance system reliability. The redundancy allocation problem has been considered for a variety of system structures; examples include series, parallel, network, parallel-series [1], and k-out-of-n [2] systems, among others. The series-parallel system is a common system structure that is used in most system designs. This paper is specifically devoted to the study of the series-parallel redundancy allocation problem.

In RAP studies, the two active and standby strategies have been traditionally employed to determine the way redundant components should be used. In standby strategy, a switching system with a non-increasing reliability function has to be used to activate a standby redundant component.

Most of previous studies have been based on the assumption that the redundancy strategy for each subsystem is fixed and predefined and that only one and the same redundancy strategy (either active [3–11] or standby [12–17]) may be employed. Standby redundancy may be further classified into the three cold, warm, and hot standby redundancy strategies as its variant forms. From among them, the cold standby is the one most often used [12–15] and warm standby has been used in fewer numbers [16,17].

It is, however, true that both active and cold-standby redundancies may be simultaneously invoked to improve upon system reliability. This rise to more realistic and flexible models Coit [18] developed a RAP formulation in which the redundancy strategy used in each subsystem was considered as a decision variable that needed to be determined. The concept of treating the redundancy strategy as a decision variable has also been used elsewhere [19–28].

For redundancy allocation problem a wide variety of solution methods have been proposed to maximize system reliability [3–8,12–14,18–24,31–35] or minimize system cost [9,10,16,30]. Some others have considered more than one objective to be optimized [11,15,17,26–29]. Most of these models have been solved using different types of meta-heuristic algorithms such as genetic algorithm [9,12,13,17,19–21,27,28,33–35], ant colony optimization [3], bat algorithm [4], variable neighborhood search algorithm [6], artificial bee colony algorithm [11], harmony search algorithm [15,31], simulated annealing algorithm [22,26], particle swarm optimization [28,29], tabu search [30], memetic algorithm [32], and a host of others [5,8,16,23].

In the redundancy allocation problem, there are different component types for each subsystem with different levels of such parameters as cost, reliability, or weight. Redundant components within a subsystem can be of the same type (that is, components in a particular subsystem are identical), or can be of different types (that is, components in a particular subsystem are non-identical) in which case component mixing will be allowed. The component mixing option has been considered in a number of studies [4,5,7,9,13,15,16,24,35] with

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the redundancy strategy taken to be active in most. Tvakkoli-Moghaddam and Safari [24] proposed a new model in which component mixing is allowed and the redundancy strategy is a standby one.

Ardakan & Hamadani [33] were the first to present a RAP they named the 'mixed strategy' model in which some (i.e., more than one) components could be active while others were standby and that components of only one type could be used in each subsystem.

The present study presents a novel model based on the mixed strategy due to Ardakan & Hamadani [33]. In this model, the redundancy strategy is considered to be a decision variable and any one of the (active, standby, or mixed) strategies may be selected for each subsystem. The main contribution of this study involves the use of mixed strategy with component mixing allowed in each subsystem. In other words, two or more types of components may be used in each subsystem and any number of the components might be either active or standby.

The rest of the paper is organized as follows. Section 2 provides a detailed description of the problem and then proceeds to model the problem described. Section 3 proposes a solution method for solving the problem. A numerical example with the computational results is reported in Section 4 to demonstrate the efficiency of the proposed methodology. Finally, in Section 5, conclusions and suggestions for future research are presented.

2. Problem formulation

In this paper, a series–parallel RAP is investigated with s subsystems under the system-level constraints of cost and weight. In this model, the selection of the redundancy strategy (active, cold standby, or mixed) is considered as a decision variable.

As previously mentioned, the main contribution of this study is the use of mixed strategy with component mixing allowed in each subsystem. As shown in Fig. 1, each subsystem can have different types of components, some of which are active while others are standby. The types of active components in each subsystem are independent of the types of standby ones. In other words, the types of active components in the subsystem may be the same as those of the standby ones, or some may be identical while others are different. The first standby component starts operation at the failure of the last active component.

Generally speaking, either of two principal scenarios (in the cold-standby and mixed strategies) is considered for failure detection and switching [14]. In the first scenario, the failure detection and switching system continually monitors system performance. When a failure is detected, a redundant component is activated. In this scenario, switch failure may occur at any point in time. Thus, whenever a failure is detected, a redundant component is activated. The switch reliability function ($\rho_i(t)$) is then a non-increasing function of time. In the second scenario, the requirement for a switch depends on failure. In other words, when a failure occurs, a switch is required. There is a constant probability (ρ_i) that the switching will be successful [20]. This paper deals only with the first scenario.

2.1. Assumptions

The goal is to design a series–parallel system such that system reliability is maximized. In addition, the following assumptions are made:

- The states of components and the related system have only two options, referred to as good or bad.
- The component attributes (i.e., reliability, cost, and weight) are known and deterministic.
- Three redundancy strategies (namely, active, cold standby, and mixed) are considered.
- There is no component repair or preventive maintenance.
- Component failures are viewed as independent events.
- Failing components do not damage the system.
- The components within the same subsystem can be of different types. In other words, component mixing is allowed.
- There is imperfect switching for the cold standby redundancy strategy.

2.2. Notations used

Indices

i	index for subsystems (i =1,2,...,s)
j	index for component types (j=1,2,...,m_i)
k_{ij}	index for the number of failures of the standby components of type j in subsystem i (k_{ij}=1,2,...,y_{ij})
l	index for the allocated component types that are standby
z_{il}	index of standby component choices used for subsystem i, z_{il}∈{1,2,...,m_i}
z_i	set of z_{il}, (z_{i1}, z_{i2}, ..., z_{iL}); for example (1, 3, 4)

Parameters

s	number of subsystems
$n_{max,ij}$	upper bound for n_{ij}, ($n_{ij} \le n_{max,ij}$; ∀i,j)
$n_{max,i}$	upper bound for n_i, ($n_i \le n_{max,i}$; ∀i)
m_i	number of available component choices for subsystem i, (i=1, 2,...,s)
t	mission time
$\rho_i(t)$	failure-detection/ switching reliability at time t
$R(t;x,y;ARS)$	system reliability at time t for designing matrix x and y and vector ARS
$R_i(t;x_i,y_i;ARS_i)$	reliability of the subsystem i at time t for designing vectors x_i, y_i and ARS_i
$r_{ij}(t)$	reliability at time t for the j^{th} available component for the subsystem i
λ_{ij}, k_{ij}	scale and shape parameters for the Erlang distribution
c_{ij}, w_{ij}	cost and weight for the j^{th} available component for subsystem i
W	system-level constraint limit for weight
C	system-level constraint limit for cost
$f_{ij}^{(k_j)}$	pdf for the $k_j{}^{th}$ failure of type j components for subsystem i at time t

Decision variables

x_{ij}	number of active components of type j used in subsystem i, (j=1, 2,..., m_i)
y_{ij}	number of standby components of type j used in subsystem i, (j=1, 2,..., m_i)
n_{ij}	number of type j components used in subsystem i (n_{ij}= x_{ij}+ y_{ij})
n_i	number of components used in subsystem i ($n_i = \sum_{j=1}^{m_i} n_{ij}$)
ARS_i	assigned redundancy strategy for subsystem i, (i=1,2,...,s)
ARS	set of ARS_i, (ARS_1, ARS_2,..., ARS_s)

2.3. Mathematical model

The problem can be formulated as follows:

$$\max \ R(t;\, x,\, y;\, ARS) \tag{1}$$

s.t.