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A model to enhance the reliability of the serial parallel systems with component mixing

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ABSTRACT

System reliability, especially for serial parallel systems, has attracted much attention in recent years. Redundancy allocation is a technique to increase the reliability of the serial parallel systems. Supplying redundant components depends on some restrictions such as available budget, weight, space, etc. This paper proposes a new model for redundancy allocation problems (RAPs) by considering discount policy. The proposed model attempts to maximize the reliability of a system by gathering various components where there are some limitations on budgeting. We present two models with different assumptions including all unit discount and incremental discount strategies. The resulted formulations are nonlinear integer models and categorized as NP-hard. Therefore, some heuristics and meta-heuristics are designed to solve the resulted models, efficiently.

1. Introduction

Serial parallel systems have a relatively complex system configuration, which can be found in different areas such as aerospace industries, manufacturing industries, telecommunication industries, computer systems, electronic systems, mechanical systems, power systems, robotic systems, automotive systems, etc. Another example could be placement of valves and pumps in nuclear facilities and obviously such systems must work properly all the time. There are different ways to enhance the system reliability. One of the prevalent ones is called redundancy allocation, which is typically an NP-hard problem [1]. Redundancy allocation problems (RAP) have been studied frequently in the literature from both problem formulation and solution approaches. Tillman et al. [2] surveyed the related works up to that time. In the area of problem formulation, RAP has been formulated for different system structures (such as series, parallel, series-parallel, parallel-series, k-out-of-n, complex, etc), different redundancies (active, standby) [3,4], and finally different objective functions of the form of maximizing the reliability of the system, minimizing the resource usages such as cost, weight, etc, minimizing entropy of the system [5], maximizing the minimum subsystem reliability [6], etc as single, bi or multiple objectives with different system level constraints [7]. Also, the RAP has been formulated for both binary state and multi state components [8]. Recently, there is an attempt to incorporate safety in RAP which is another important system's requirement along with reliability [9].

In all the presented models, one can argue that they do not deal with real world assumptions in calculating the cost of the system. In general, RAP involves with determining the number of components in parallel, i.e. redundancy levels, along with selecting the suitable components from among multiple choices subject to constraints on the whole system. The components may differ in terms of reliability, cost, weight, manufacturing, quality assurance, etc. As the number of components increases,

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the cost of the system also increases which is not desirable since most of the time there are some budget limitations. In reality, vendors provide some facilities to encourage customers to buy more. One of them is discount on the quantity of buys. Keeping this fact in the mind, our literature review discloses that no work in the literature considers discount factor in the budget constraint. In this paper, we fill this gap and model the traditional redundancy allocation problem for serial parallel systems considering both all unit discount and incremental discount strategies. In addition, these discount strategies can be considered for all the models mentioned above.

In the area of the solution approach, mathematical programming techniques, heuristic and meta-heuristic methods are employed. Prasad and Kuo [10] overviewed the methods developed for solving various reliability optimization problems. The mathematical programming techniques restrict the solution space and include branch and bound [11,12], integer programming [13], dynamic programming [13–17], linear programming [18,19], column generation [20], surrogate constraint [21], etc. Heuristic and meta-heuristic approaches include genetic Algorithm [22–25], Tabu Search [26], Ant System [27], Variable Neighborhood Descend algorithm [28], Variable Neighborhood Search [29], Particle swarm optimization [30], Honey bee mating algorithm [31], etc.

The discount models proposed in this paper are more complicated than the traditional model and cannot be solved within a reasonable time framework. Therefore, two heuristics and meta-heuristics are proposed in this paper to deal with the proposed redundancy allocation problems with component mixing and price discounting. The proposed meta-heuristic is based on honey bee mating optimization (HBMO) technique, which is a swarm intelligence-based approach in which the mating–flight can be seen as a set of transitions in a state-space. Apart from other algorithms which are based on foraging behavior of bees, three kinds of bees, i.e. the queen, the drones and the workers are considered and, accordingly, a number of procedures can be applied inside the swarm. This characteristic differentiates the HBMO technique from other population based algorithms such as genetic or memetic algorithms. Another advantage of this method is that each brood uses parts of the solutions of the one queen and more than one drone. Besides, the workers play the role of local search phase in the algorithm. The algorithm originally was proposed by Abbas [32,33] and it has been implemented to different applications [34–36]. Recently, it has been applied to RAP [31] which leads to promising results.

The remainder of this paper is structured as follows. Section 2 describes the problem under study along with the related mathematical models. Section 3 presents the proposed solution procedures. The experimental results are brought in Section 4. Finally, the paper is concluded in Section 5.

2. Problem description

The studying issue of this paper involves with the redundancy allocation problem with component mixing in which the components are different in terms of reliability, cost and weight. The solution of this problem, simultaneously determines the optimal combination of components and redundancy levels so that the reliability of the entire serial parallel system is maximized. Apparently, increasing the redundancy level accompanies with cost that is restricted by available budget. In today's competitive world, presenting a new system design with lower finished price while maintaining high reliability can make companies more popular amongst customers. Therefore, manufacturers are willing to provide the necessary parts and components in lower price so that the finished price is in a desired value. On the other hand, suppliers offer discount on their supplies regarding the quantity of orders to encourage customers to buy more. There are different discount strategies in the market. In this paper, we make use of all unit discount and incremental discount policies to formulate the discounted RAP with component mixing. In the following, first we overview the general RAP with component mixing and then proliferate it with discount assumption.

2.1. Mathematical model for RAP with component mixing

The mathematical model of the general redundancy allocation problem with m constraints and multiple component choice is shown in model (1) [31]. Fig. 1 demonstrates the serial parallel system configuration with alternative components. In this paper, we consider only cost and weight constraints.

$$Max\ z = \prod_{i=1}^{S}\left[1 - \prod_{j=1}^{Ti}(1 - R_{ij})^{Nij}\right], \quad (1)$$

S.T.

$$\sum_{i=1}^{S}\sum_{j=1}^{Ti} a_{ijk}N_{ij} \leqslant b_k, \quad k = 1, \ldots, K,$$

$$\sum_{j} N_{ij} \geqslant 1, \quad i = 1, 2, \ldots, S,$$

$$N_{ij}\ \text{integer} \quad i = 1, .., S, \quad j = 1, \ldots, T_i, \quad (2)$$