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Allocation and sequencing in 1-out-of-N heterogeneous cold-standby systems: Multi-objective harmony search with dynamic parameters tuning

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A B S T R A C T

A redundancy allocation is a famous problem in reliability sciences. A lot of researcher investigated about this problem, but a few of them focus on heterogeneous 1-out-of-N: G cold-standby redundancy in each subsystem. This paper considers a redundancy allocation problem (RAP) and standby element sequencing problem (SESP) for 1-out-of-N: G heterogeneous cold-standby system, simultaneously. Moreover, here, maximizing reliability of cold-standby allocation and minimizing cost of buying and time-independent elements are considered as two conflict objectives. This problem is NP-Hard and consequently, devizing a metaheuristic to solve this problem, especially for large-sized instances, is highly desirable. In this paper, we propose a multi-objective harmony search. Based on Taguchi experimental design, we, also, present a new parameters tuning method to improve the proposed algorithm.

1. Introduction

The system reliability optimization is very important in the real world applications. Many designers are devoted to improving the reliability of manufacturing systems or product elements to be more competitive in the market [1]. The importance of reliability in systems conceptions has been growing with advances on technologies in order to avoid failures. Reliability can be defined as the probability for a system does not fail during an interval of time in which the system must be working [2].

Since in systems, there are human errors, poor maintenance and else, failure in each subsystem is unavoidable [3] and we must reduce the probability of failure. In this regards, mainly, there are two techniques for improving the system reliability:

1. Improving reliability of each element: this way can increase reliability of elements, but this technique is not well for all times, because improving the reliability of elements needs much time to redesign them and sometimes, this way becomes extremely costly and cannot provide desirable reliability of system [4].
2. Use of structural standby redundancy: in general, there are three groups of redundancy strategies; hot, cold and warm standby strategies. In the first strategy (hot standby), the redundant units start to operate simultaneously with the primary online unit. This standby technique is generally used for applications. The second strategy (cold-standby) technique is commonly used and in which the standby elements do not operate until the primary element failed and standby element replace with defective element. The last redundancy strategy is warm standby that compromizes the hot and cold. Examples of the warm standby systems are redundant hard disks used to replace the failed disks in a storage system. Other examples of warm standby are in power plant and wireless sensors network [7].

The main aim of this paper is to consider the cold-standby allocation and sequencing problems that includes redundancy allocation and standby element sequencing with 1-out-of-N: G heterogeneous cold-standby systems as a multi-objective optimization problem. The sequencing of cold standby element is important and the restoration cost for standby elements is related to the time of remaining in standby condition and all of the elements have time-dependent cost, so in this study, we consider two objectives cold-standby system reliability and the sum of buying and time-independent costs. Since this problem is NP-hard [6], use of a metaheuristic algorithm can be appropriate and in this paper as well as a multi-objective metaheuristic, a new dynamic parameters tuning is also proposed to improve the metaheuristic algorithm.

The organization of this paper is given as follows. In Section 2, problem definition, the problem modeling, assumptions, notations and mathematical model are explained. In Section 3 the harmony

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search algorithm as a solving methodology are introduced. Moreover, in this section, solution encoding and interpretation of the dynamic tuning of the algorithm's parameters are explained. Section 4, presents the experimental design related to compare of the dynamic parameters tuning against the static parameters tuning and finally, Section 5 states our conclusions and further researches.

2. Literature review

Since 1960s, researchers have tried to solve the serial-parallel redundancy allocation problem [8]. One of the first papers that investigated on the redundancy allocation problem is Fyffe et al. [9]. The redundancy allocation problem is NP-hard; consequently, in the literature different metaheuristics have been proposed. Liang and Chen [10] used a variable neighborhood search algorithm for redundancy allocation of series-parallel systems. Safari [11] used a type of Non-dominated Sorting Genetic Algorithm-II (NSGA-II) to solve a multi-objective redundancy allocation problems. In this study, the redundancy strategy for each subsystem is not predetermined and each solution consists of (*i*) redundancy strategy, *i.e.*, selecting between cold redundancy and active redundancy, and (*ii*) elements and levels of redundancy in each subsystem. The objective functions of this study are maximizing system reliability and minimizing total system costs in which time-to-failure distribution of all elements is Erlang distribution. Najafi et al. [12] considered mean time to failure of the series–parallel system as a objective function that must be maximize by optimal allocation of redundancy with cold standby.

Garg and Sharma [3] used a particle swarm optimization to solve the multi-objective reliability-redundancy allocation problem. In this study, the problem was transformed into fuzzy multi-objective optimization problem with fuzzy decision variables. Levitin et al. [13] was the first researcher that considered a standby element-sequencing problem of 1-out-of-N: G heterogeneous cold-standby systems with an objective of minimizing the expected system mission cost. 1-out-of-N: G heterogeneous cold-standby system means that one element puts in the operation and it remains in operation and other elements wait in the cold standby mode until the first element destructed then other non-identical elements that have been in the cold standby mode put into operation. Zhang et al. [14] used a bare-bones multi-objective particle swarm optimization for redundancy allocation problems and pruned the Pareto-optimal set by using data clustering. Lin and Chang [15] evaluated the reliability of a manufacturing system that has multi-state with reworking operations in each machine. Sadeghi et al. [16] optimized a bi-objective problem that it consists of minimizing of the total supply chain cost (one-vendor multi-retailers-vendor managed inventory model) and maximizing of the production system reliability using the active redundancy allocation structure. They also proposed NSGA-II and non-dominated ranking genetic algorithm (NRGA) to solve this problem. Taghizadeh and Hafezi [17] evaluated a supply chain constituent's reliability of a car-producing factory in Iran by helping the supply chain operations reference model, however, in this study, they do not use of optimization method for improving the system reliability. Chen et al. [18] studied the model of diagnosis reliability of supply chain with common cause failure that was constructed by fault tree analysis. In this study, Chen et al. used a simulation algorithm to measure reliability of supply chain. Garg et al. [19] used redundancy-allocation to improve the reliability of Pharmaceutical Plant. This system consists of subsystems that are organized in series. Weighing Machine, Sifter Machine, Mass Mixer, Granulator, Fluid Bed Dryer, Octagonal Blender, Rotary Compression Machine, Coating Machine, Air compressor and Strip Packing Machine are subsystems of Pharmaceutical Plant. Levitin et al. [7] proposed a genetic algorithm (GA) for a standby element sequencing problem for 1-out-of-N: G heterogeneous warm-standby systems with non-identical elements and expected mission cost of warm standby systems.

Levitin et al. [20] optimized the SESP problem of 1-out-of-N: G non-repairable heterogeneous cold-standby systems subject to phased-mission systems. In this study, to minimize the expected mission cost, they proposed a GA to generate the initial sequence of elements that tries considering system reliability constraint. Levitin et al. [21] modeled the standby element sequencing problem of the k-out-of-n: G heterogeneous cold-standby system as a constrained optimization problem with the objective of minimizing the expected mission cost. Levitin et al. [22] minimized the expected mission operation cost for systems/subsystems with mixed hot and cold redundancy types. For this problem, they assumed the system consists of N elements.

General methods for analyzing and estimating of the reliability of cold standby are simulation [12], universal generating function (UGF) [13], central limit theorem [23] and numerical analysis method [24]. Among these methods, using numerical analysis method is more flexible in comparison with other methods, because it can be used for 1-out-of-N cold standby systems, K-out-of-N cold standby systems, warm standby systems and other models [24].

This review clearly reveals that there is a tangible gap in the literature of reliability problem so that there is a on research that considered RAP and SESP for 1-out-of-N: G heterogeneous cold-standby system, simultaneously, as a multi-objective optimization. We can also see that almost all of the papers considered single objective problems. In this paper, 1-out-of-N: G heterogeneous cold standby is used for improving reliability of system that its structure is series, redundancy structure is used for increasing the agility and improving reliability of each subsystem. This system is given in Fig. 1, schematically.

3. Problem definition and modeling

3.1. Assumptions

Since different constraints and assumptions can result in different problems, we introduce the following characters which are considered in this paper.

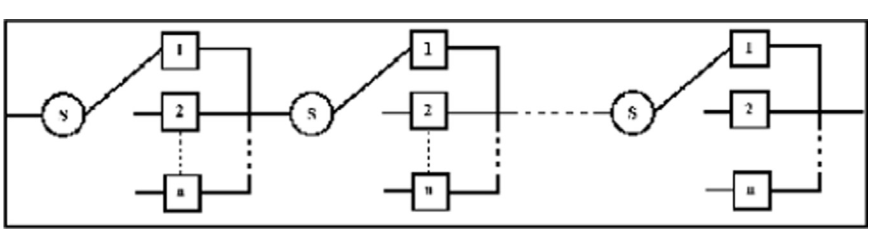

Fig. 1. Cold standby system with n item in each subsystems.