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A multi-objective optimization problem for multi-state series-parallel systems: A two-stage flow-shop manufacturing system

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ABSTRACT

This research investigates a redundancy-scheduling optimization problem for a multi-state series parallel system. The system is a flow shop manufacturing system with multi-state machines. Each manufacturing machine may have different performance rates including perfect performance, decreased performance and complete failure. Moreover, warm standby redundancy is considered for the redundancy allocation problem. Three objectives are considered for the problem: (1) minimizing system purchasing cost, (2) minimizing makespan, and (3) maximizing system reliability. Universal generating function is employed to evaluate system performance and overall reliability of the system. Since the problem is in the *NP*-hard class of combinatorial problems, genetic algorithm (GA) is used to find optimal/near optimal solutions. Different test problems are generated to evaluate the effectiveness and efficiency of proposed approach and compared to simulated annealing optimization method. The results show the proposed approach is capable of finding optimal/near optimal solution within a very reasonable time.

1. Introduction

The system reliability engineering is concerned with improving the reliability/performance of the systems, especially in complex systems such as nuclear powers, powerhouses, etc. In system reliability engineering, an element is considered as an entity that cannot be further subdivided. In binary reliability structure, an element can have two states: perfect performance and complete failure [1]. In multi-state systems, elements may be in different states which represent different performance rates of the element. Please note that performance rate in this research is referred to the working level which a manufacturing machine is working. For example, 100% performance rate means that the machine is working at its highest speed and therefore jobs are process with the minimum processing time possible. In order to improve the reliability/performance of a system, redundancy strategy can be employed. There are two kinds of redundancy strategies: active and standby. In active redundancy strategy, all the redundant components are in use at time zero while only one of them is needed at any given time. On the other hand, standby redundancy strategy is categorized into three different types; namely cold, warm and hot. In the cold standby redundancy strategy, system components do not fail before they are used. In the warm standby redundancy strategy, the probability of failure of redundant components is more than zero, but less than the failure probability of the operating components. In the hot standby redundancy strategy, the failure pattern of the system's components does not depend on whether it is working or in the standby mode, which is quite similar to the active redundancy strategy in terms of mathematical formulation [2]. The redundancy allocation problem (RAP) is concerned with optimizing the system reliability based on the system budget and system weight through designing the optimal combination of working and redundant elements. However, when the elements of a system are manufacturing machines which can fail to function properly, any performance reduction decreases the processing time of the machine as well as the whole manufacturing system. Consequently, RAP can be employed to improve the stability of the manufacturing system through designing a system with redundant elements which results in a lower completion time of jobs and improving the efficiency of the manufacturing system. As a result, in this paper a joint redundancy-scheduling problem (RSP) is proposed for such manufacturing system to optimize the reliability of the system, total cost, and minimizing the makespan. Commonly, a manufacturing machine works at different performance rates which depend on the condition of the working machine. Therefore, a manufacturing machine should be considered as a multi-state element which constructs a series-parallel multi-state RSP. In this research, the manufacturing system is considered to be a flow shop system which manufactures different products. Redundant elements

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are redundant machines that become active when the working machine fails to work properly. In a manufacturing environment, when a machine is idle, the probability of a breakdown is lower than when it is working on a job. On the other hand, this probability is not equal zero. Accordingly, warm standby redundancy approach should be used for proposed RSP. There are some researches related to RSP problem in the literature. Ouzineb et al. [3] proposed a hybrid genetic algorithm-tabu search approach to deal with redundancy allocation problem and expansion scheduling problem. Sarhan [4] improved the structure of reliability equivalence from simple series and parallel systems to complex systems. Then, Sarhan et al. [5] made different designs of a four independent and identical components in a series-parallel system. They compared different designs of the system to the original one and improved the reliability of the system. Ramirez-Marquez and Coit [6] proposed a new solution methodology for the redundancy allocation problem in the multi-state series-parallel system with capacitated binary components which is shown to be efficient in dealing with such problems. Sharma et al. [7] studied the heterogeneous redundancy allocation problem for a multi-state series-parallel system. The ant colony optimization approach was proposed to handle the problem through finding the optimal/near optimal structures of the system. Watcharasitthiwat and Warkein [8] presented an improved ant colony algorithm solving the communication network design considering economics and reliability aspects of network design. Azaron et al. [9] proposed a genetic algorithm (GA) for solving a multi-objective discrete reliability optimization problem in a k dissimilar-unit non-repairable cold-standby redundant series-parallel system. Coelho [10] studied the reliability-redundancy optimization problems considering the combination of Gaussian distribution and chaotic sequence and an efficient PSO algorithm was presented to handle the problem. Tavakkoli-Moghaddam et al. [2] proposed a GA for solving the redundancy allocation problem when either active or cold standby redundancy can be selected for individual subsystems. Tian et al. [1] proposed an approach for the redundancy optimization in a multi-state series-parallel system in which the main goals were to determine the optimal redundancy level for each parallel subsystem and obtain the optimal values of the variables which influenced the component state distribution for each subsystem. They used Markov approach for identifying the component state distributions considering the component state transition rates and they also used the universal generating function (UGF) approach for determining the system state distribution. Sheikhalishahi et al. [11] presented a novel hybrid GA–DEA algorithm in order to solve multi-objective k -out-of- n problem and determine preferred policy. The proposed algorithm maximizes overall system reliability and availability, while minimizing system cost and queue length, simultaneously. Sheikhalishahi [12] considered maintenance activity planning, and several outputs including machines and operators' availability, reliability, efficiency and queue length are computed. Since the problem is multi-criteria, data envelopment analysis (DEA) method is used to select the preferred policy.

Levitin [13] considered the scheduling of multi-state series parallel system with the availability constraint and employed GA to obtain optimal results. The main goal of the problem is to minimize the cost of system and satisfy the availability constraint. Levitin et al. [14] used a GA based on the UGF method for solving the redundancy-reliability optimization for the power system as a multi-state series-parallel system with different element capacities. Agarwal and Gupta [15] proposed a heuristic for homogeneous redundancy optimization of a series-parallel system in order to minimize the cost of the system when the minimum acceptable reliability level of the system is satisfied. Azadeh et al. [16,17] developed a new approach for maintenance policy and planning problem by integrating simulation and data envelopment analysis methods. Levtin et al. [18] developed an efficient procedure using a GA which is based on UGF for evaluating the availability of series-parallel multi-state system and minimizing the cost. Levitin [19] suggested a procedure for evaluating the reliability function of non-repairable series-parallel multi-state system considering common cause failures (CCF). Levitin et al. [20] proposed a methodology in which UGF method is used to evaluate the reliability of the system and employed GA to solve a family of multi-state system reliability optimization problems including structure optimization, maintenance optimization, optimal expansion and optimal multi-stage modernization. Taboado et al. [21] proposed a GA incorporated with UGF to solve a multiple objective multi-state reliability optimization problem. Components were different in terms of performance levels, cost, weight and reliability. The objectives are minimizing total cost and maximizing the system availability, simultaneously. Tian et al. [22] proposed a model for a multi-state series-parallel system in order to determine the optimal redundancy for each stage and optimal component state distribution, simultaneously. They demonstrated that the presented reliability-redundancy allocation model is more effective and efficient than the current redundancy allocation problems. Li et al. [23] considered a multi-objective system reliability optimization problem using a two-stage approach including finding Pareto optimal solution at the first stage in which a multiple objective evolutionary algorithm (MOEA) was applied, and an integrated multiple objective selection optimizations (MOSO) solution was employed at the next stage. Li et al. [24] presented the optimal model for multi-state series-parallel system to formulate a system considering common cause failures for its elements. The results indicate that the redundancy allocation problem is affected by the common cause failure. Lisnianski and Ding [25] proposed a new method including UGF and random processes methods for reliability evaluation of the repairable multi-state systems. Ahmadizar and Soltanpanah [26] considered a reliability optimization problem in series system. To maximize the reliability of the system with multiple-choice and budget availability, an efficient ant colony optimization was applied. Sahoo et al. [27] formulated four different multi-objective optimization problems for maximizing the system reliability and minimizing the system cost using GAs and Pareto optimization concept.

To the best knowledge of the authors, there is no study which considers redundancy allocation problem for job scheduling and reliability optimization problems, simultaneously, for a multi-state series parallel system. As mentioned before, a flow shop system is assumed in which each machine may process a job in different performance rates according to a given set of probabilities. Different performance rates affects the processing time of a job. Consequently, the overall performance of the system can be enhanced by the use of redundancy allocation approach. Basic redundancy allocation problem is in the *NP*-hard class of combinatorial optimization problems. Thus, the presented problem is categorized as an *NP*-problem as well. GA, as an efficient meta-heuristic approach, is employed to deal with this complexity of the problem. Moreover, UGF method is used to evaluate the reliability of the any proposed solution to the problem. The methodology used in this paper is described in details in the following sections.

The rest of this paper is organized as follows. Section 2 describes the problem in details. Proposed GA is introduced and explained in Section 3. In Section 4, test problems are defined and computational results are provided. Section 5 investigates the validation and verification of proposed solving algorithm. Finally, Section 6 draw conclusions on the current research work.

1.1. Motivation and signification

None of the previous studies have considered the effect redundancy allocation on job scheduling problem for multi-state series parallel systems, especially for a two stage flow shop manufacturing system. They also have not considered the decreased performance effects on processing time of jobs. Thus, the redundancy strategy could be used to minimize the completion time. In this research, a