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A bi-objective multi-period series-parallel inventory-redundancy allocation problem with time value of money and inflation considerations

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A B S T R A C T

A large number of existing research studies on reliability redundancy allocation problems do not take into consideration the time value of the money and the inflations costs associated with the component inventories. In this study, we formulate a multi-component multi-period series-parallel inventory redundancy allocation problem (SPIRAP) as a mixed-integer nonlinear mathematical model where: (a) the costs are calculated by considering the time value of money and inflation rates; and (b) the total warehouse capacity to store the components, the total budget to purchase the components and the truck capacity are subject to constraints. The primary goal in this study is to find the optimal order quantity of the components for each subsystem in each period such that the total inventory costs are minimized and the system reliability is maximized, concurrently. A controlled elitism non-dominated ranked genetic algorithm (CE-NRGA), a NSGA-II, and a multi-objective particle swarm optimization (MOPSO) are presented to solve the proposed SPIRAP. A series of numerical examples are used to demonstrate the applicability and exhibit the efficacy of the procedures and algorithms. The results reveal that the CE-NRGA outperforms both NSGA-II and MOPSO.

1. Introduction

The implementation of redundancy plays an important role in elevating the reliability of a system. The redundancy allocation problem (RAP) engages the selection process of components and a series, parallel or series-parallel design configuration to simultaneously optimize some objective functions, such as system reliability, cost and weight, given certain design constraints (Zhang & Chen, 2016). RAP is crucial to design any modern complex systems such as safety systems, electrical power systems, transportation systems, satellite systems, and telecommunication systems with very strict reliability requirements (Wang & Xu, 2009). In the recent decade RAP has been common issue for investigation among the researchers. Salmasnia, Ameri, and Niaki (2016) modeled a series-parallel RAP in which the system reliability was maximized and the total cost became minimized. An electromagnetism-like mechanism meta-heuristic algorithm was developed by Teimouri, Zaretalab, Niaki, and Sharifi (2016) to solve a RAP. Kong, Gao, Ouyang, and Li (2015) introduced a RAP with multiple strategy choices at which both active redundancy and cold standby redundancy could be considered. They used a particle swarm optimization to optimize their problem. Mousavi, Alikar, Niaki, and Bahreininejad (2015b) formulated a multi-objective multi-state RAP in a series-parallel system in a fuzzy environment where the component types in each subsystem were identical. Mousavi, Alikar, and Niaki (2015) Optimized a fuzzy series-parallel RAP in which all types of the components in each subsystem were homogenous. A fruit fly optimization population-based meta-heuristic algorithm was derived to solve the problem.

Supplying the products and handling the products are the most important factors in today's businesses to reduce the total cost which is an essential goal for most companies. The companies try

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to utilize the best methods and approaches to reach this purpose given the constraints of real world applications. Therefore, more attention should be given by researchers to studying the inventory management aspects of business systems. In RAP the authors have focused more on the installation and the selection process of the components on the system and there is only a few works in the literature studying the production or preparing process of the components. Sadeghi, Sadeghi, and Niaki (2014) addressed a two-objective vendor managed inventory and redundancy allocation problem in a vendor-retailer supply chain problem. The aim of the problem was to obtain the optimal number of machines working in series to manufacture a single product. Xie, Liao, and Jin (2014) solved the system reliability of a repairable k-out-of-n RAP where the spares inventory in addition to redundancy allocation of components were taken into account.

In this work the costs imposed on the system are calculated under the time value of money and inflation rates which are two important factors associated with costs. Dey, Mondal, and Maiti (2008) developed an inventory problem for deteriorating items under inflation and time value of money at which two storages i.e. the one owned by the company and the rented one were available to store the items. A production repairing inventory control problem under inflation and the time value of money in a fuzzy environment was proposed by Mondal, Maity, Maiti, and Maiti (2013) where some parts of the spoiled items were repaired to be sold out. Mousavi, Hajipour, Niaki, and Alikar (2013) considered a multi-item multi-period inventory control problem in which the shortages were not allowed and both the time value of money and inflation rates were investigated to compute the total inventory costs. They used the genetic algorithm (GA), the simulated annealing (SA) algorithm and the branch and bound method to solve their problem. Wu, Skouri, Teng, and Hu (2016) modeled a seasonal/-fashionable inventory control problem under the time value of money where the items were deteriorating during the time. Yadav, Singh, and Kumari (2015) presented an inventory control problem in which the buyers could pay for the items at the end of period. The inflation rate, the deterioration rate and the delay in payment were considered in their model. Pareek and Dhaka (2014) formulated an inventory control problem for deteriorating products where shortages were not allowed, the deterioration rates were fuzzy values and the inflation and time value of money were calculated in modeling the total costs. An inventory control system was proposed by Duari and Chakraborti (2015) for deteriorating items with an exponentially increasing demand rate where shortages were allowed with inflation discount rates and delay in payment.

There are a variety of the related works on the inventory control problem recently in the literature (Cárdenas-Barrón, Sarkar, & Treviño-Garza, 2013; Kumar & Kumar, 2016; Sarkar, 2012, 2013, 2016; Sarkar & Majumder, 2013; Sarkar, Sana, & Chaudhuri, 2010; Sarkar & Saren, 2015; Sarkar, Saren, & Cárdenas-Barrón, 2015; Sarkar, Saren, & Wee, 2013; Sarkar & Sarkar, 2013; Sarkar, Sarkar, & Yun, 2016; Sett, Sarkar, & Goswami, 2012). Furthermore, Mousavi, Sadeghi, Niaki, and Tavana (2016) formulated a bi-objective multiple items multiple period inventory control problem in which shortages were allowed. The aim was to find out the optimal order quantity of items so that the total inventory costs and the total storage space were minimized simultaneously. The model was optimized using the three algorithms of MOPSO, NSGA-II and NRGA where the results were in the favor of MOPSO. Moreover, there are also some supply chain works related to this research performed recently in the literature (Pasandideh & Asadi, 2016; Pasandideh, Niaki, & Maleki, 2015). In addition, a number of works have recently considered the economic production order quantity problem (Jawla & Singh, 2016; Saxena, Singh, & Sangal, 2016; Shukla, Tripathi, & Sang, 2016).

Meta-heuristic algorithms have been common for solving the complex problems which have been hard to be optimized by exact solution methods. Multi-objective problems are not exempted from this complexity while many of researchers have implemented the multi-objective version of meta-heuristic algorithms to solve their problems. While the RAP is shown to be strongly NP-hard, a multi-objective meta-heuristic algorithm called the controlled elitism non-dominated ranked genetic algorithm (CE-NRGA) is developed to find the Pareto solutions of the problem under investigation. This algorithm is an elite version of NRGA has been used in many works in the literature. Pasandideh, Niaki, and Asadi (2015) addressed a multi-product multi-period inventory problem for a three-echelon supply chain problem in which a non-dominated sorting genetic algorithm (NSGA-II) and a NRGA were applied to solve their problem. Jalali, Seifbarghy, Sadeghi, and Ahmadi (2015) utilized a NRGA, a multi-objective biogeography-based optimization algorithm and a multi-objective simulation annealing algorithm to optimize a stochastic multi-facility location allocation-supply chain problem. A multi-objective vendor managed inventory was modeled by Sadeghi and Niaki (2015) for a single vendor multiple retailers supply chain problem in which NRGA and NSGA-II were used to find the Pareto solutions of the problem. Shahsavar, Najafi, and Niaki (2015) applied a NRGA to solve a multi-objective project scheduling problem with a triple-objective including (i) the minimization of the makespan, (ii) the minimization of the total cost associated with the resources, and (iii) the minimization of the variability in resources usage. Govindan, Jafarian, Khodaverdi, and Devika (2014) presented a multi-objective facility location problem for a two-echelon multiple vehicles routing problem by integrating sustainability in decision-making, on distribution in a perishable food supply chain network. NRGA, NSGA-II, and multi-objective particle swarm optimization (MOPSO) algorithms were implemented to solve the problem. Table 1 shows the recent literature most related to the current study.

The main novelties of the current work are: (i) considering a multi-components multi-period inventory control system for a series-parallel RAP, (ii) calculating the total inventory costs under the time value of money and inflation and (iii) deriving an elite version of NRGA called CE-NRGA, a NSGA-II and MOPSO to solve the problem.

The rest of the paper is organized as follows. In Section 2, we define the parameters, notations and decisions variables applied to formulate the problem. We also outline the proposed problem in detail along with a flowchart in this section. In Section 3, we describe and formulate the bi-objective SPIRAP problem. In Section 4, we present the multi-objective meta-heuristic algorithms proposed in this study. Some numerical examples and the analytical comparisons of the algorithms are generated in Section 5. Finally, in Section 6, we present our conclusion and future research directions.

2. The problem parameters and definition

In this section, we first define the parameters, notation and decision variables then outline the problem.

2.1. Notations

The indices, notations, parameters and the decision variables used to formulate the SPIRAP are described below: