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A bi-objective continuous review inventory control model: Pareto-based meta-heuristic algorithms

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ABSTRACT

In this paper, a bi-objective multi-product (r,Q) inventory model in which the inventory level is reviewed continuously is proposed. The aim of this work is to find the optimal value for both order quantity and reorder point through minimizing the total cost and maximizing the service level of the proposed model simultaneously. It is assumed that shortage could occur and unsatisfied demand could be backordered, too. There is a budget limitation and storage space constraint in the model. With regard to complexity of the proposed model, several Pareto-based meta-heuristic approaches such as multi-objective vibration damping optimization (MOVDO), multi-objective imperialist competitive algorithm (MOICA), multi-objective particle swarm optimization (MOPSO), non-dominated ranked genetic algorithm (NRGA), and non-dominated sorting genetic algorithm (NSGA-II) are applied to solve the model. In order to compare the results, several numerical examples are generated and then the algorithms were analyzed statistically and graphically.

1. Introduction

Inventory model as a main issue of production management has been studied widely during the last decades. In inventory models, determining the order quantities of products is one of strategic decisions. One of the models that has been attended over the past years, is the (r,Q) model in which an order of size Q should be placed when the inventory level drops to a reorder point r. In the (r,Q) model, the problem is determining the economic order quantity Q and the economic reorder point r.

In many real inventory systems with regard to stochastic demand, some costumers may encounter with shortage. In other words, when the system is out of stock and the supply and demand are not in the same size, two different situations may occur: if the customer, whose needs are not critical at that time, will wait for the item to be fulfilled, then the demands will be backordered (backorder case) but if the costumer cannot wait and fulfills the demand by another supplier, then all the demands are lost (lost sales case). Das [1] and Yano [2] considered a stochastic (r,Q) inventory system with complete backordering. Buchanan and Love [3] presented the lost sales case for a special inventory system with Poisson demands and Erlang lead times. Kim and Park [4] proposed a stochastic inventory model in which a fraction of stock-out is backordered and the rest of the demand is lost. Axsater [5] provided a good review of the models dealing with continuous review policies for inventory systems. Salameh et al. [6] considered a (r,Q) inventory system in which delays in retailers' payments could happen immediately after the receipt of the order or till the next replenishment order. Zhang et al. [26] proposed an inventory control system with continuous review policy and considered Poisson demands and constant lead time in their model. Hill [7] presented a continuous review lost sales inventory model with a Poisson demand process. Mitra [8] analyzed a deterministic model under continuous review inventory model in a multi-echelon system including suppliers, depots and distributors. Tajbakhsh [9] considered a continuous review (r,Q) inventory model with a fill rate service constraint and relaxed the assumption that the distribution of lead time demand is known. Zhao et al. [10] studied a multi-item continuous review inventory model with regarding resources' limitation and stochastic demands. Alaghebandha and Hajipour [11] presented a mathematical model for a multi-product continuous review inventory model and considered warehouse spaces, service level, number of shortages and cost of expected shortage limitations and finally used an ICA algorithm to solve the proposed model. Saracoglu et al. [12] formulated a multi-product inventory models as an integer linear programming which considers some constraints such as capacity constraint and budget limitation and finally developed a genetic algorithm to solve their problem.

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Most of the relevant researches in the (r,Q) model, consider a single objective problem. For example some researches attempted to define the economic order quantity and reorder point through minimizing the total cost of the inventory system. Some other studies considered maximization of service level in an inventory system. Despite of these single objective models, some researches considered several objectives simultaneously and provided multi-objective models. Agrell [13] proposed a multi-criteria framework for an inventory control system and determined lot size and safety stock (service level). Mahapatra and Maiti [14] presented a multi-objective inventory model and involved the impact of quality level into the demand function. Mandal et al. [15] considered a multi-objective fuzzy inventory model and used geometric programming method to solve it.

All of the abovementioned works applied a weighting approach to convert the multi-objective problem to a single one. In the recent years, some researches applied meta-heuristic approaches to solve the multi-objective inventory models. Among algorithms used for multi-objective problems, non-dominated sorting genetic algorithm (NSGA-II) is a commonly used Pareto-based algorithm proposed by Deb et al. [16]. This algorithm is applied in different areas of industrial and operational management. Bhattacharya and Bandyopadhyay [17] employed NSGA-II for solving conflicting bi-objective facility location problem. Chambari et al. [18] implemented NSGA-II to solve a bi-objective redundancy allocation problem. Mehdizadeh and Tavakkoli-Moghaddam [19] proposed a new meta-heuristic optimization algorithm, namely vibration damping optimization (VDO), which is based on the concept of vibration damping in mechanical vibration. They first utilized the VDO algorithm to solve the parallel machine scheduling problem. This algorithm simulates the vibration phenomenon. In addition, Mehdizadeh et al. [20] proposed a hybrid VDO algorithm to solve the multi-facility stochastic-fuzzy capacitated location-allocation problem. Furthermore, Mousavi et al. [21] developed a special type of the VDO algorithm to solve capacitated multi-facility location–allocation problem with probabilistic customers' locations and demands. In the recent years, according to the efficiency of this algorithm for single-objective problems, many researchers attempt to use this algorithm for multi-objective problems. Hajipour et al. [22] introduced multi-objective version of VDO called MOVDO to solve the multi-objective optimization problems. Hajipour et al. [23] applied MOVDO for solving redundancy queuing facility location-allocation problem. Based on Atashpaz-Gargari and Lucas [24] presented a new kind of evolutionary algorithm, called imperialist competitive algorithm (ICA), which is inspired by a social phenomenon. They used this algorithm for some benchmark problems to show its ability in finding good solutions.

Tsou [25] used a multi-objective particle swarm optimization (MOPSO) algorithm to solve the inventory system. Tsou [26] developed his algorithm and applied an improved version of MOPSO (IMOPSO) in which a local search is used to enhance the convergence to the Pareto-optimal front. He also employed a clustering technique to the non-dominated archive to control the speed and diversification of the search. Moslemi and Zandieh [27] presented a comparison of some recent improving strategies on MOPSO algorithm in continuous review stochastic inventory control system.

Unlike many researches in which a single objective (r,Q) inventory model is considered, in this paper a bi-objective continuous review (r,Q) inventory model with regard to backordering of the shortage, storage space limitation and budget constraint is presented. The first objective function aims to minimize the total cost of the system, consist of holding cost, ordering cost and shortage cost and the second objective function, maximizes the service level through minimizing the cumulative distribution of the demands. Considering these objective functions simultaneously, on one side leads to reduce the total cost of the system and on the other side helps in having more satisfied customers with regarding to service level issue. Furthermore, according to the complexity of the proposed bi-objective model, two novel Pareto based multi-objective approaches including MOVDO and MOICA are used to solve the bi-objective model and the results are compared with other Pareto based approaches including MOPSO, NRGA, and NSGA-II which have been employed a lot in the literature to solve multi-objective models.

The rest of this paper is organized as follows: in Section 2, the parameters and variables are defined and then the bi-objective multi-product (r,Q) model is formulated. In Section 3, the multi-objective Pareto-based meta-heuristic algorithms are explained. Next, the results and comparisons are analyzed in Section 4. Finally, the conclusion and further research suggestions are given.

2. Model description

In this paper, a bi-objective multi-product inventory system is considered in which the inventory level is reviewed continuously. It is assumed that the demand of each product is a continuous random variable with a uniform probability density function $f(x_i)$ and cumulative distribution function $F(x_i)$. The inventory control policy of this system is a (r,Q) policy. Based on this policy which is a generalization of the *EOQ* model, when the inventory level reduces to the level r, an order of size Q should be placed [28]. It is assumed that shortage is allowed for each product and it can be backordered [29]. Also a budget constraint and limited storage capacity are considered in the model.

This paper formulates the abovementioned multi-product inventory system as a bi-objective model in which the first objective function attempts to minimize the total cost of the system and the second objective function tries to maximize the minimum of the service level, simultaneously. The problem is finding the optimal order quantity and reorder point for each product with regard to mentioned objective functions.

2.1. Notations

Assumptions

- Shortage could occur as backorder
- The demand for each product during the lead time is stochastic and has a continuous uniform distribution function
- The rate of annual demand for each product is fixed
- The budget is limited
- Storage space of the warehouse is limited

Parameters

N	number of products
CP	maximum capacity of warehouse
B	maximum budget for producing safety stock
h_i	annual holding cost per unit of product i
μ_i	expected demand of product i
π_i	annual shortage cost per unit of product i in backorder situation
k_i	maximum shortage level of product i
$f(x_i)$	probability density function of realized demand for product i
x_i	random variable of realized demand for product i
$F(x_i)$	cumulative distribution function of realized demand time for product i
$\bar{b}(r_i)$	averaged shortage of product i per cycle
C_i	purchasing cost per unit of product i
D_i	demand rate of product i unit per year
S_i	storage space per unit of product i
a_i	fixed ordering cost of product i