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A genetic algorithm for a joint replenishment problem with resource and shipment constraints and defective items

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ABSTRACT

A joint replenishment problem (JRP) is presented to determine the optimal reordering policy for multiple items with defective quantity and several restrictions such as shipment constraint, budget constraint, and transportation capacity constraint. The objective is to minimize the total expected cost per unit time. A two-dimensional genetic algorithm (GA) is provided to determine an optimal family cycle length and the reorder frequencies. A numerical example is presented and the results are discussed including the effect of defective items on the ordering policy. Extensive computational experiments are performed to test the performance of the GA. The JRP was also solved by a differential evolution (DE) algorithm and the results obtained from DE were compared with those obtained from GA.

1. Introduction

A joint replenishment problem (JRP) is defined as the coordination of the replenishment of a group of items that may be ordered jointly from a single supplier (Goyal, 1974). One of the advantages of jointly placing order for a group of items is sharing the fixed cost associated with order, and hence the total cost is reduced when compared to the cost of individually placing order for each item (Moon and Cha, 2006). Moreover, a JRP is a good practice to reduce transportation cost, when a vehicle is used to transport multiple items simultaneously. Similarly, the supplier's set-up cost can be reduced by manufacturing multiple items using the same facility. One of the disadvantages of the JRP is increasing the average inventory level and system control costs. In order to solve the basic JRP, family cycle time and the frequency of replenishing individual items have to be determined while minimizing the total cost, which is the sum of ordering and holding costs. Most of the studies related to the basic JRP have usual assumptions such as deterministic and constant demand, linear holding cost, no shortage, and no quantity discount (e.g., Khouja and Goyal, 2008; Robinson et al., 2009).

The JRP has received considerable attention over the last few decades and different solution approaches have been proposed to solve the JRP. For example, Shu (1971), Goyal (1974), and Silver (1975) proposed a simple procedure to determine the order quantity for multiple items in a JRP. Moreover, many heuristics have been developed to solve different versions of JRP, namely, basic JRP, JRP with quantity discount, and constrained JRP using various methods including direct and indirect grouping strategies, genetic algorithm (GA), evolutionary algorithm (EA), RAND, QD–RAND, and C-RAND (e.g., Kaspi and Rosenblatt, 1983, 1991; van Eijis et al., 1992; Hariga, 1994; Wildeman et al., 1997; Khouja et al., 2000; Cha and Moon, 2005; Moon and Cha, 2006; Olsen, 2008; Hong and Kim, 2009). However, among many heuristics, GA and EA have been proved to be effective for solving the JRP (Olsen, 2008). Moreover, it was concluded that solutions obtained from GA combined with a local search algorithm and RAND are very close to the global optimum (Hong and Kim, 2009). Recently, Wang et al. (2012) proposed a differential evolution (DE) algorithm based on Storn and Prince (1997) to solve a JRP and claimed that the DE algorithm can solve a JRP more effectively than the EA used in Olsen (2008). Hence, in this research, we used GA and DE, which are the best algorithms existing in the literature, to solve a JRP. With respect to GA literature, we used a two dimensional chromosome representation. There are several studies on two-dimensional GA for solving packing problem (e.g., Herbert and Dowsland, 1996; Bortfelldt, 2006), cutting problem (e.g., Ono and Ikeda, 2008), and knapsack problem (e.g., Bortfelldt and Winter, 2009). In addition, the two-dimensional GA was also implemented in different areas of research, for example, ising problem (Anderson et al., 1991) and photonic crystal slab (Jia et al., 2009). With respect to DE, Storn and Prince (1997) proposed a novel DE to

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solve a complex continuous non-linear functions and we used a similar algorithm to solve the JRP.

Most of the studies on JRP assumed that items included in an order can be shipped together without any restrictions. However, in practice, there are restrictions or dependency among the items. As a result, though an order is placed for certain items at the same time, they cannot be shipped together in the same truck. For example, chemical or fragrant products should not be shipped together with dry food or food ingredients, since the odor will be absorbed by the dry food or food ingredients. Another example is ambient products, which are not shipped with fresh produce and ready to eat meals due to different storage temperatures. Recently, several studies (e.g., Olsen, 2008; Wang et al., 2012) considered such interdependency of the items in a JRP. However, these studies assumed that such interdependency increases minor ordering costs to maintain different requirements of the prohibited items in the same truck and then the JRP was solved by using direct and indirect groupings. Let us consider a modern retail business company, which operates in Thailand, having restrictions in its shipment policy to maintain quality and food safety. This company does not allow transporting prohibited items in the same truck at all. This retail company plans its ordering policy to minimize its total inventory related cost considering quality and safety requirements of the company. Then, the company provides the ordering policy to a third-party logistics provider and it ships the items for a fixed transportation cost. Hence, the JRP models in Olsen (2008) and Wang et al. (2012) cannot be applied to this retailer. In order to solve the retailer's JRP, in this paper, without changing minor setup costs of items having restrictions, shipment restrictions or interdependency of the items are included in the constraints and then a constrained JRP is solved. In addition, there are several other constraints besides shipping restrictions or interdependency of items. For example, Goyal (1975) introduced a JRP with budget constraint. Khouja et al. (2000) addressed the issue of maximum load constraint in a JRP. Later, Moon and Cha (2006) also studied a JRP with a budget constraint. However, the existing literature on JRP does not consider such constraints simultaneously in a JRP. In this research, we included budget constraint and transportation capacity constraint with interdependency of the items and then solved a constrained JRP.

Another important aspect in a JRP is defective items. Wahab et al. (2011) pointed out that many Thai small and medium enterprises implemented total quality management, however buyers still sometimes find defective items in the shipments, and it is also possible that some items may also get damaged during shipment. There are several studies dealing with defective items in a single item replenishment such as EOQ, for example, Porteus (1986), Rosenblatt and Lee (1986), Salameh and Jaber (2000), Cárdenas-Barrón (2000), Goyal and Cárdenas-Barrón (2002), Papachristos and Konstantaras (2006), Maddah and Jaber (2008), and Wahab and Jaber (2010). The defective items in shipments will affect the ordering policy. For example, if there are more defective items in the shipment, the order quantity should be higher to compensate for those defective items. Hence, this study also considered the percentage of defective items in the JRP to investigate its effect in the ordering policy.

The purpose of this research is to model a constrained JRP for multiple items, where each item has a certain percentage of defective item in each shipment, with constraints such as dependency among items (i.e., some items have restrictions that they cannot be shipped together in the same truck), budget constraint, and transportation capacity constraint. Such a JRP exists in many real business applications. For example, this problem can be found in a retailer that delivers products from its distribution center to retail stores. The JRP is solved by using a two-dimensional GA and DE. The results obtained from both GA and DE are compared.

This paper is organized as follows: Section 2 presents the model, notations, and decision variables. Section 3 presents the solution methodology, a two-dimensional GA, and its steps. Section 4 illustrates numerical examples and also presents the comparison between GA and DE. Section 5 concludes the paper.

2. The model

This section first presents indices, parameters, and decision variables of the model and then describes the JRP step by step to develop the model.

2.1. Indices, parameters, and decision variables

Indices

i an index of an item, where $i = 1, 2, \ldots, n$

j an index of a truck that is used to ship items, where $j = 1, 2, \ldots, J$

l an index of a set representing items that can not be shipped together, where $l = 1, 2, \ldots, L$

Parameters

n the number of items

J the number of trucks

L the number of sets of items that cannot be shipped together

Δ_j the capacity of truck j

D_i the demand rate for item i

Q_i the order quantity for item i

a_i the handling cost for item i

μ_i the unit screening cost for item i

ν_i the lost per defective unit for item i

p_i the percentage of defective of item i

x_i the screening rate for item i

t_i the screening time for item i

h_i the holding cost per unit of item i per unit time

c_i the unit variable cost for item i

K the ordering cost per order

B the amount of capital that can be invested

S_l the lth set of items that cannot be shipped together

Decision variables

T time interval between replenishment for a set of items

m_i the integer number of intervals that the replenishment takes place for item i

b_{ij} the proportion of item i transported by truck j

$$Y_{ij} \begin{cases} 1 & \text{if item } i \text{ is ordered and delivered by truck } j; \\ 0, & \text{otherwise.} \end{cases}$$

2.2. The joint replenishment problem

Item i has demand D_i per year. It is assumed that demand for each item is deterministic and constant, and shortages are not allowed. Item i is ordered in every m_ith replenishment cycles, where m_i is a positive integer, meaning the replenishment quantity of item i will last for m_iT period of time. This also indicates that the cycle time for item i is m_iT.

An important aspect that has been addressed in this problem is the restriction in shipping. That is, because of the nature of the products and requirements, some items cannot be shipped together. For example, chemical or fragrant products should not be shipped in the same truck as dry food or raw material. Though