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A parameter-tuned genetic algorithm for multi-product economic production quantity model with space constraint, discrete delivery orders and shortages

Seyed Hamid Reza Pasandideh [a,1], Seyed Taghi Akhavan Niaki [b,*], Jalil Aryan Yeganeh [c,2]

[a] Department of Railway Engineering, Iran University of Science and Technology, Tehran, Iran
[b] Department of Industrial Engineering, Sharif University of Technology, Tehran, Iran
[c] Department of Management and Accounting, Shahid Beheshti University, Tehran, Iran

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ABSTRACT

In this paper, a multi-product economic production quantity problem with limited warehouse-space is considered in which the orders are delivered discretely in the form of multiple pallets and the shortages are completely backlogged. We show that the model of the problem is a constrained non-linear integer program and propose a genetic algorithm to solve it. Moreover, design of experiments is employed to calibrate the parameters of the algorithm for different problem sizes. At the end, a numerical example is presented to demonstrate the application of the proposed methodology.

1. Introduction and literature review

The economic production quantity (EPQ) is one of the most applicable models in production and inventory control environments. This model can be considered as an extension to the well-known economic order quantity (EOQ) model that was introduced by Harris [1] in 1913. Regardless of the simplicity of EOQ and EPQ, they are still applied industry-wide today [2].

In spite of wide acceptance, some practitioners and researchers have questioned the practical applications of the EOQ model due to several unrealistic assumptions regarding model input parameters. These parameters are setup costs, holding costs and demand rate. For example Woolsey [3] severely critiqued the use of the EOQ model, arguing that the assumptions (i.e. constant demand, fixed carrying capacity, constant price, unlimited storage capacity, and paying for the price of items as soon as they are received) necessary to justify the use of this model are not met in real world environment. This has motivated many researchers to modify the EOQ model to match real-life situations. Chang et al. [4] developed an EOQ model for deteriorating items, in which the supplier provides a permissible delay to the purchaser if the order quantity is greater than or equal to a predetermined quantity. Li et al. [5] developed EPQ-based models with planned backorders to evaluate the impact of the postponement strategy on a manufacturer in a supply chain. They derived the optimal total average costs per unit time for producing and keeping end-products in a postponement system and a non-postponement system, respectively.

Another key assumption of both the basic EOQ and EPQ models is that stock-outs are not permitted. In inventory systems, when a shortage occurs, unfilled demands become either backorders or lost sales. If all customers cancel their orders and turn them to other suppliers lost sales will result (see [6] for an instance). However, when all customers are willing to wait for delivery a full backorder occurs. Wee et al. [7] developed an optimal inventory model for items with imperfect quality and shortage backordering. Many researchers have studied inventory models with partial backordering which is a mixture of back orders and lost sales. San Jose et al. [8] studied an inventory model with partial backlogging, where unsatisfied demand is partially backlogged according to an exponential function.

In recent years, several researchers have applied genetic algorithms (GAs) as an optimization technique to solve the production/inventory problems. For example Zhao and Wang [9] developed an EOQ model for multi-item and multi-storehouse with limited funds, limited storage capacity and stochastic demand. In

* Corresponding author. Tel.: +98 21 66165740; fax: +98 21 66022702.
E-mail addresses: pasandid@yahoo.com (S.H.R. Pasandideh), niaki@sharif.edu (S.T.A. Niaki), jalil.1361@yahoo.com (J.A. Yeganeh).
[1] Tel.: +98 21 77491029; fax: +98 21 77451568.
[2] Tel.: +98 21 29902383; fax: +98 21 22431843.

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order to solve the model, they provided a hybrid genetic algorithm that combines self-adapting crossover operator and mutation operator. There are several interesting and relevant papers related to the application of GA in inventory problems such as Stockton and Quinn [10], Mondal and Maiti [11], Hou et al. [12], Gupta et al. [13], Lotfi [14], Pal et al. [15], and Taleizadeh et al. [16–19].

Pasandideh and Niaki [20] developed a multi-product EPQ model with limited warehouse space. They assumed that the orders may be delivered discretely in the form of multiple pallets. In their models shortages and delays were not permitted. Under these conditions, they formulated the problem as a non-linear integer-programming model and proposed a genetic algorithm to solve it.

In this paper, we extend Pasandideh and Niaki [20] model to include shortages. We assume that all shortages are completely backordered. Other conditions and constraints are the same as their work.

The rest of the paper is organized as follows. The problem along with its assumptions is defined in Section 2. In Section 3 the problem is mathematically formulated. After a brief introduction in Section 4, a genetic algorithm is proposed to solve the model. In Section 5, design of experiments (DOE) is used to analyze the performance of the proposed GA. This analysis is important in improving the performances of the proposed GA by identifying the optimal values of its control parameters. Section 6 includes results of applying the proposed genetic algorithm to a numerical example. The conclusion and recommendations for future research are given in Section 7.

2. Problem definition

Consider a production company that works with a supplier. The situations by which the company and the supplier interact with each other are defined as follows:

(a) The supplier produces all of the demanded products with known and constant rates.
(b) The demand for each product in the company is known with a constant rate.
(c) The supplier sends the orders to the company by pallets.
(d) The company pays the transportation cost of each pallet.
(e) The company determines the capacity of each pallet and the number of shipments.
(f) The warehouse space of the company for all products is limited.
(g) The setup and holding costs are known.
(h) Shortages are allowed and unsatisfied demands are fully backlogged.

The problem is to determine the order quantity, the pallet capacity, the number of shipments for each product, and the maximum shortage level of each product such that the total inventory cost is minimized while the constraints are satisfied.

3. Problem modeling

In order to mathematically formulate the problem we take advantage of the classical EPQ model and extend it to the problem at hand. We note that while in the classical EPQ model orders are produced by the supplier with constant and continuous rates, are shipped to the customer, and there is no limitation on the warehouse space, for the problem at hand the deliveries are made in the form of several discrete pallets and the space is limited.

In order to model the problem, first we define the parameters and the variables in Section 3.1. Then, we pictorially demonstrate the situation by inventory graphs in Section 3.2. Different costs are derived in Section 3.3. Finally, we present the model of the problem in Section 3.4.

3.1. Variables and parameters

For products $i = 1, \ldots, n$, we define the variables and the parameters of the model as follows:

D_i demand rate
P_i production rate
Q_i order quantity
T_i cycle time
T_{p_i} effective production time per cycle
T_{d_i} non effective production (down) time per cycle
t_i time between two consecutive pallet shipments
k_i pallet capacity
m_i number of shipments per cycle
B_i maximum shortage (backorder) level
$I_{\max}$ maximum on-hand inventory level
f_i space occupied by each unit
d_i transportation cost per shipment
c_i providence cost per unit
A_i setup cost per cycle
b_i backordering cost per unit per time unit
h_i holding cost per unit per time unit
TT_i total transportation costs per year
TP_i total providence costs per year
TS_i total setup costs per year
TB_i total backordering costs per year
TH_i total holding costs per year
TC total costs of all products per year
n number of products
f available warehouse space for all products

3.2. Inventory graph

The situation of the inventory problem of this research is similar to the one of EPQ model; the differences are in the delivery types and the shortages. In this paper, an order of the ith product, after being produced by the supplier, will be delivered to the company in m_i pallets each with capacity of k_i. A graph of the inventory position of product i over time is illustrated in Fig. 1.

In Fig. 1, each jump in T_{p_i} section shows a delivery of a pallet to the company with capacity of k_i. During T_{p_i} and T_{d_i} sections the company consumes the delivered products at constant rate. When the inventory position is positive, there is inventory on hand and the company incurs holding cost. When the inventory is negative, the demand is backordered and the company incurs backorder cost. In order to calculate the holding and backordering costs, we need to know the number of jumps in T_{p_i} section. The total number of jumps is m_i. Accordingly, $Q_i = m_i k_i$ is correct.

Referring to Fig. 1, during the interval $(0, 2t_i)$ the supplier faces backorder cost only. However, while during interval $(2t_i, 5t_i)$ the supplier faces both holding and backordering costs, in interval $(5t_i, 7t_i)$ he faces only holding costs. Besides, from $7t_i$ to the (zero level) point, the supplier incurs only holding cost; and from that point to the end of the cycle only backorder cost. Let Z_1 be the number of jumps in interval $[0, 2t_i)$ and Z_2 be the number of the jumps in interval $[0, 5t_i)$. Then, it turns out that

$$Z_1 = \left\lfloor \frac{B_i - D_i t_i}{k_i - D_i t_i} \right\rfloor \tag{1}$$

$$Z_2 = \left\lfloor \frac{B_i}{k_i - D_i t_i} \right\rfloor \tag{2}$$

Hence, the number of the jumps during interval $[0, 2t_i)$ is Z_1, during interval $[2t_i, 5t_i)$ it is $Z_2 - Z_1$ and in interval $[5t_i, 7t_i)$ it is $m_i - 1 - Z_2$. For instance in Fig. 1, $Z_1 = 2$, $Z_2 = 5$ and $m_i = 8$.