IJMA | International Journal of Management and Administration

Year:5, Volume:5, Number:9 / 2021

DETERMINATION OF THE COST-EFFECTIVE LOT-SIZING TECHNIQUE FOR PERISHABLE GOODS: A CASE STUDY

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ABSTRACT

Determining the exact needs to meet the demand in manufacturing enterprises is an important factor in terms of the efficiency of the production environment. Businesses can make accurate decisions about which material to order in what quantity through the Material Requirements Planning system. At this point, the methods used in determining lot-size are among the effective tools in order amount decision. One of the sectors where material order quantities are critical is the food sector, as it includes perishable goods.

In this paper, it is aimed to determine the cost-effective lot- sizing method that will minimize the cost for an enterprise producing gum which is a perishable goods. For this purpose, 10 different lot-sizing methods were used for three different products with real data obtained from a company produces gum. The performances of the techniques were evaluated. A comparison was made for three types of gum in terms of number of orders, order cost, holding cost and total cost according to the cases with and without shelf life constraints and the method that minimizes the total cost was sought. When the results of the study were considered, it was seen that different methods yielded the cost-effective results for the cases with and without shelf-life constraints pertaining to the criteria of the number of orders, order cost, inventory holding cost and total cost criteria. However, it has been observed that the multi-echelon optimization method created to be peculiar to the firm yielded the result with a lower cost than the others.

Key words: Lot-sizing techniques, perishable goods, shelf life, MRP

JEL: M11, C610, L66

1. Introduction

Determining the exact needs to meet the demand in manufacturing enterprises is an important factor in terms of the efficiency of the production environment. Businesses can make accurate decisions about which material to order in what quantity through the Material Requirements Planning system. Quantity and time data of materials in inventory management are critical input data for the MRP system to work accurately and completely. While determining the clear requirements to meet the demand, the decision of how much to order can be made by lot size determination techniques. Lot-size determination is the process of determining the lot sizes of the order or work order given to suppliers or production centers in order to meet the production or purchasing requirements in the most appropriate way. Determination of lot-size is the calculation of the final product or its components that will minimize the total cost to meet the demands arising during the planning periods.

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Of the oldest and most widely used lot-sizing and decision model, the chief method is the Economic Order Quantity (EOQ), which was developed in 1913 by Ford W. Haris and is based on some mathematical calculations (Schroeder, 1993; Bushuev et al., 2015) The studies initiated with this method were continued by studying with classical inventory control methods for the goods with independent and dependent demand structures by means of the deterministic models when the demand was known and by means of the stochastic models when the demand fitted the stochastic distribution (Eroglu, 2002). However, it is inappropriate to compute the order quantity for the goods with a dependent demand structure by means of the classical inventory control methods (Russel et al. 2006). Fixed order quantity (FOQ), Economic order quantity (EOQ), Lot for lot (L-4-L), Periodic order quantity (POQ), Least Unit Cost) (LUC), Least Total Cost) (LTC), Part Period Balancing) (PPB), the Wagner-Whitin algorithm (WW) and the Silver-Meal method (SM) can be given as widely used examples of the single-echelon methods which find the cost-effective lot size. These methods vary according to whether the system to be implemented is single- or multi-echelon, whether it is stochastic or deterministic, and the structure of products (Narasimhan et al., 1995; Rahim et al., 2014). However, it is not possible to make a precise comparison about which algorithms give better results. The fact that the data used is for trial purposes, that is, they do not belong to real systems, and that the systems studied have very different characteristics make this comparison impossible (Ozyoruk, 2003).

One of the sectors where material order quantities are critical is the food sector, as it includes perishable goods. Effective management and control of production resources throughout the chain from raw material supply to production, from storage to distribution of products is of strategic importance for enterprises in this sector. Since the products in the food sector have a critical feature as they affect public health, companies in the sector try to minimize the risk at every level of the supply chain. Excessive orders and production volumes, especially in quantities to be considered waste, can lead businesses to situations that can cause economic and, perhaps worst, loss of prestige. Food supply chains involve limited shelf life, demand and price variability and are therefore difficult to manage and more complex than other supply chains (Ahumada & Villalobos, 2009). The most important factor that makes production planning complicated in the fresh food sector is that the products have a certain shelf life. Accordingly, offering a product with a later expiry date to the customer is always a competitive advantage. Therefore, shelf life is a critical issue for production scheduling and MRP system applications in this industry. It is difficult to determine the shelf life of foods as there is so much variety. It is impossible to accurately determine the shelf life. Each company can develop a unique method (Alican, 2009)

In this paper, it is aimed to determine the cost-effective lot- sizing method that will minimize the cost for an enterprise producing gum which is a perishable goods. For this purpose, 10 different lot-sizing methods were used for three different products with real data obtained from a company that produces gum. The performances of the selected lot-size determination techniques were evaluated. Today, thanks to advanced technology (automation, software, sensors etc.) these amounts are determined accurately, but in this study, it is aimed to contribute to the literature by considering 10 different methods in the manufacture of perishable products. As Qui et al. (2019) stated in their work, the inclusion of perishable inventory is very important in both lot size and production orientation problems. Deciding how much to produce is critical and is affected by the spoilage rate of products with perishable inventory.

The paper is organized as follows: After this section, in which the introduction and a general introduction of the study is made, the second section where perishable goods and determining the lot size are expressed is given. After the section 3 where the definition of the problem was made, the section 4 where the results of the methods discussed and the evaluation according to the results was presented. Finally, section 5 presents discussions.

2. Lot-Sizing for Perishable Goods

For food products, the lot size is determined considering different criteria due to their short shelf lives and perishability in terms of the product structure. It is possible to classify lot-sizing methods in perishable goods as follows:

A-Lot sizing in perishable goods with a fixed life

1. Deterministic lot-sizing methods in perishable goods with a fixed life
2. Stochastic lot-sizing methods in perishable goods with a fixed life

B-Lot sizing in perishable goods with a variable life

1. The method of periodic review policy as the lot-sizing method in perishable goods with a variable life
2. The exponential distribution method as the lot-sizing method in perishable goods with a variable life

The lot size of perishable goods is based on the economic lot size model and is related to the tradeoff between storage and sale of manufactured goods; Storage of perishable goods creates a holding cost and the goods disappear over time. Lot sizing decisions are based on the classic economic order quantity (EOQ) model; Therefore, there is a great deal of literature on extended EOQ models that combat the degradation of perishable inventory.

Giri & Chaudhuri (1998) studied in their paper deterministic models of perishable inventory with stock-dependent demand rate and nonlinear holding cost. Muriana (2016) presented an EOQ model for perishable products with fixed shelf life under stochastic demand conditions. Abad (2003) investigated the pricing and lot sizing problem of perishable goods with finite production under spoilage and partial back-order conditions. Abad (2003) proposed a model by assuming that a delay in orders might be allowed instead of bearing the perishing cost of a product in perishable goods. What differs in this model is the allowing of a delay in some of the orders under the conditions in which the case of delay is economically more appropriate by thinking that the customers will not be patient with waiting. Teng et al. (2007) further expanded this model, also dealt with the loss of prestige value by the enterprise, and made a comparison for utility with the model developed by Goyal and Giri (2003) and providing a solution to the production-inventory problem which considered the demand, production, and perishing rates that varied by time. In 1993, Sarker and Babu (1993) addressed the Abad-like method and showed that reducing the manufacturing lead time sometimes yielded a more effective result when the processing costs were not taken into account. In their study, in which they intended to optimize the manufacturing lead time and the production rate also similarly considering the shelf life in 1997, Viswanathan and Goyal (1997) disregarded the case of lost sales. On the other hand, with the model they proposed in their study that they addressed within the scope of single-constraint and multi-item pricing, Shavandi et al. (2012) aimed at enabling to take a pricing decision which was as good as that in the production and inventory decisions maximizing the total utility. In the model they developed, they considered perishable goods in three categories as substitute, complementary, and independent.

Problems with the production of perishable goods, (1) batch sizing decisions, (2) planning decisions, and (3) a combination of both (Shin et al, 2019). Over the years, there has been a significant increase in research into modeling and optimizing the food supply chain system. In the study of Lemma et al. (2014), they focused on operational issues that cause perishable food loss or waste, and made a review on modeling and optimization techniques for perishable products.

Solution methods should be sought by classifying the goods when making a study on perishable goods. Nahmias (1978) divided perishable goods in two different groups:

- Goods with a fixed life: They are goods the shelf life of which is definite beforehand and the perishing of which can be addressed independently of time. The utility provided by the products decreases in time and the product finally completes its life. Such products as blood and vegetables can constitute examples of this group.
- Goods with a random life: They are goods the life of use of which cannot be determined beforehand and the perishing probability distribution of which is expressed with the gamma distribution. Electronic devices and chemicals can be given as examples of the products in this group.

This classification also imposes some constraints and obligations for the products. Many products produced in industry have very short periods of validity or use under the influence of many constraints like the shelf life constraint. In such cases, enterprises try to minimize basic costs such as production cost, holding cost, set-up cost, and lost sale cost. In Silver's model (1989), in which he assumed that reducing the production rates would not bring about any additional cost, in his study that also considered the shelf life constraint in 1989, Silver (1989) proved that reducing the production rates yielded a better result than reducing the manufacturing lead time. Later on, he worked on a new approach to the EOQ model, but in this study by him, he emphasized the production costs by disregarding the shelf life constraint (Silver, 1990). In their study, where they used the Fourier series to find the holding cost of the supplier in 2006, Huang and Yao (2006) developed a search algorithm in which they intended to minimize the total cost for perishable goods in a single-supplier and multi-customer system. Another important study on this subject was published by Raafat (1991) and minimized the total cost also considering the costs of lost orders and delayed orders.

In this study, however, it is used what the approach to the minimization of the total production cost considering the number of orders, order cost, holding cost, and total cost in a single-echelon way.

Besides such elements as order cost, holding cost, lost orders, and delay cost in perishable goods, the perishing cost of a product was either reflected on the problems in different ways or neglected. In the study, also disregarded the perishing cost of the product, the delay cost, and the case of lost sales and make a comparison of more than one lot-sizing method in terms of order and holding costs in an applied fashion with the data obtained from a real food enterprise.

In the case of goods with a fixed life, the goods are kept in stock for a specific period in order to satisfy the demand and then discarded. In such goods, it is assumed that the utility provided by the product does not decrease until the shelf life expires. Algorithms in which perishing is never allowed are generally used in cases with a fixed shelf life and a deterministic demand. One of the most used methods is the EOQ method (Viswanathan and Goyal, 1997). Besides, in a study published in 1960 and intended to determine the optimum quantity in cases of periodic review and a known demand, Veinott showed that it would be appropriate to order as many as the demand when FIFO was used. Nevertheless, the shelf lives of all goods are not always fixed. Especially in the production of fresh products, the value of the product varies by time. The perishable product used in this study is gum and included in the category with a fixed life. Hence, 10 different methods such as the EOQ method, the modified EOQ method, and the POQ method were addressed in this study. These methods are used as lot-sizing methods in not only the goods with a fixed life but also the perishable goods with a variable life (Friedman and Hoch, 1978; Nahmias1975).

Hence, it is possible to classify these methods according to a single product or multiple products, whether the demand is stochastic or deterministic, a single period or multiple periods, the models in which reductions in quantity and lost sales both are and are not allowed, and fixed and variable perishing rates. In the light of all this provided information, the main purpose of this study is to select the cost-effective method to minimize the cost by using 10 different lot-sizing methods for two different cases, i.e. with and without shelf life constraints, in perishable goods. The optimum method for this firm was determined with the real data obtained from a firm which produced gum. Within this scope, identification of the problem was presented in the second section, application of the selected methods in the third section, and the cost-based performance analysis for each method in the following section.

3. Identification of the Problem

This study was applied with the data taken from a company which produced gum in Turkey. Because accurate and clear data are critical for the correct operation of techniques, the company was chosen for its thoroughness in obtaining the necessary data and for sharing clear and reliable information. However, it should be stated that much more valid results are likely to be achieved in companies where shelf life and perishability characteristics are more critical, especially in milk and dairy products, meat, fish products and pharmaceutical and pharmaceutical industry products.

The firm desires to reduce the order and holding costs for three types of products which were predominantly produced. These costs directly affect the production cost. Although gum is a product with the shelf life constraint, it has a longer shelf life than other perishable goods. Therefore, the purpose of this study in the lot-sizing method is to minimize the order and holding costs so as to reduce the production cost. According to the Turkish Food Codex (TGK, 2015) gum is not as sensitive as other perishable goods. There is no such obligation that each gum has to contain a best-before date individually, and its shelf life is 18-24 months. Since there are no sudden fluctuations in demand and as they generally do not have health-threatening effects as other perishable goods even if their shelf life expires, the shelf life constraint may also be disregarded. Thus, ten different methods, also mentioned above, were employed in perishable goods by using the data of the enterprise on the basis of two approaches – i.e. with and without shelf life constraints – in the study.

Figure 1 presents the locations of the three products under examination in the bill of material and the quantities required to produce a unit of the product. Some 1.45 g of 4011575 is required to produce a unit of 4015016 and 0.74 g of 4011574 is required to produce a gram of 4011575.

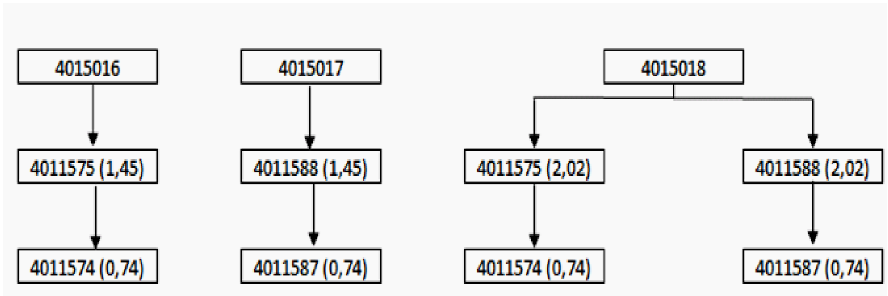


Figure 1 The bill of material for the three products under examination

The demands for the three products produced in the same production line are provided in Table 1. Demands with longer periods were not included and the planning horizon was confined to 6 months since it was not allowed to produce the products with a longer period than 6 months altogether under the structure of the enterprise and the customer did not accept products older than 6 months.

Table 1. 6-month demands for the products

PRODUCT	1	2	3	4	5	6	General Total
4015016	4,680	9,000	4,320	4,320	4,320	4,320	30,960
4015017	1,440	5,220	2,700	2,700	2,700	2,700	17,460
4015018	672	924	336	420	504	504	3,360
General Total	6,792	15,144	7,356	7,440	7,524	7,524	51,780

Table 2 shows the holding costs (monetary unit of Turkey-TL /inventory) of the finished- and semi-finished products and the values of the set-up periods required for product replacements. The transition between the products lasts half an hour in end products. A set-up period of 1.2 hours is predicted for cleaning and reloading processes in the semi-finished products at Echelon 1, whereas a set-up period of 1.5 hours is predicted for similar processes in the semi-finished products at Echelon 2.

By disregarding the set-up period, the order period/cost was calculated as 13 Turkish Lira (TL) per order for Echelon 0, as 15 TL for Echelon 1, and as 16 TL for Echelon 2. However, the cost of set-up periods was considered within the order cost, for it was repeated each time a new order was placed. Hence, the order cost was computed as 227 TL for Echelon 0, as 1,200 TL for Echelon 1, and as 4,560 TL for Echelon 3.

4. The Performances and Evaluations of Lot-Sizing Methods

The first criterion among the criteria considered when evaluating each method applied is the minimization of the total cost, whereas the other criteria are the order cost, the holding cost, and the number of orders.

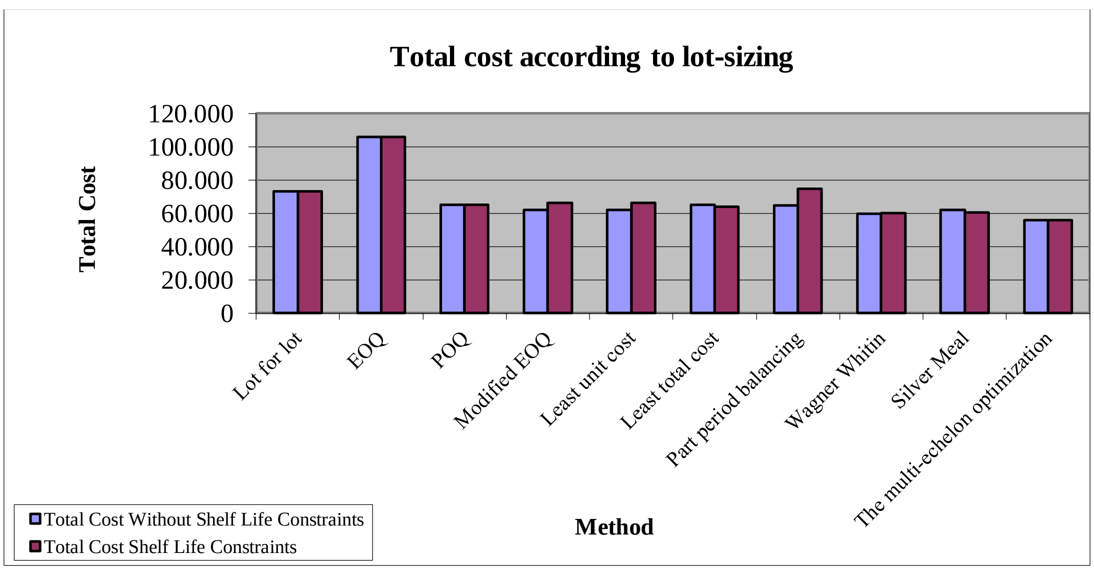
The total cost results obtained from the calculations of all methods used with and without shelf life constraints are presented in Table 2. As it will be seen from Table 2 and Figure 2, the EOQ method draws attention as the method with the highest cost in terms of total cost. This is because the economic order quantities resulting from the lower order costs than the holding cost were very low for Echelon 0, while the EOQ values turned out very high and the holding costs increased due to very high order costs at the other echelons. The lowest total cost value was not provided by the Wagner-Whitin method, as expected, but by the multi-echelon optimization equation established.

Table 2. A comparison of the lot-sizing methods according to their total costs

Method	Total Cost	
	without the Shelf Life Constraint	**with the Shelf Life Constraint**
Lot for lot	73,206	73,206
EOQ	106,045	106,045
POQ	65,047	65,047
Modified EOQ	61,901	66,486
Least unit cost	61,901	66,486
Least total cost	65,013	64,025
Part period balancing	64,765	74,917
Wagner-Whitin	59,773	60,301
Silver-Meal	62,113	60,408
Multi-echelon inventory optimization	55,864	55,864

The graph concerning a comparison of each of the lot-sizing methods used according to their total costs is presented in Figure2.

Figure 2. A comparison of the lot-sizing methods according to their total costs



On the other hand, a comparison of the lot-sizing methods according to the number of orders is presented in Table 3.

Table 3. A comparison of the lot-sizing methods according to the number of orders

Method	**Number of Orders**	
	without the shelf life constraint	**with the shelf life constraint**
Lot for lot	42	42
EOQ	32	32
POQ	36	36
Modified EOQ	36	36
Least unit cost	36	36
Least total cost	31	31
Part period balancing	30	32
Wagner-Whitin	35	37
Silver-Meal	34	36
Multi-echelon optimization	31	27

Figure 3 and Table 3 demonstrate the numbers of orders by method. What is surprising is that the number of orders suggested by the EOQ method is greater than that of the method of lot for lot. The reason for this has been expressed above while describing the graph of total cost. The striking point here is that an increase in the number of orders was observed when the shelf life constraint was added to the other methods, while there was a decrease in the number of orders when the shelf life was added as a constraint to the results obtained with optimization.

Figure 3 A comparison of the lot-sizing methods according to the number of orders

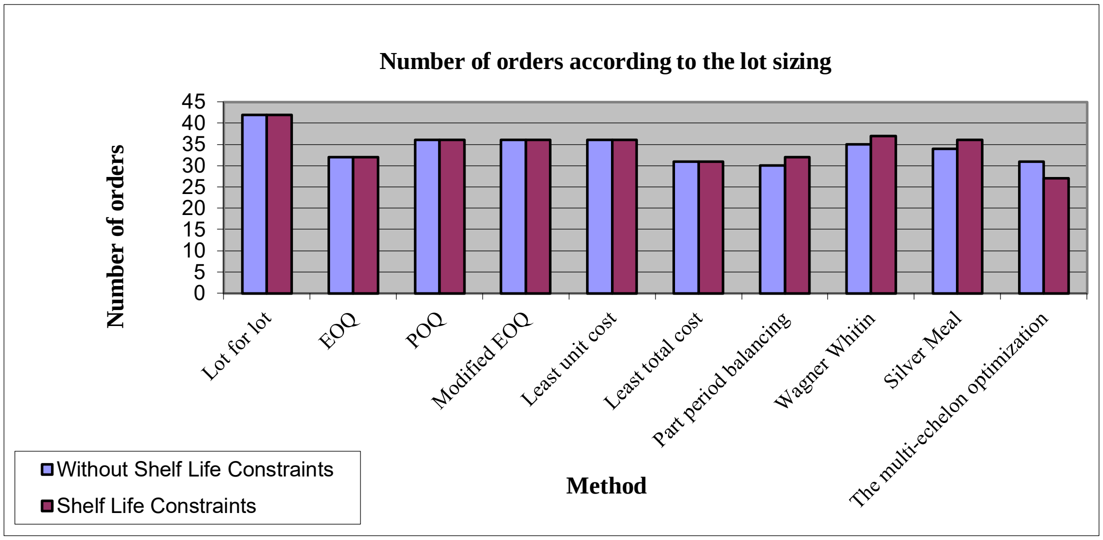


Table 4. A comparison of the lot-sizing methods according to the order costs

Method	Order cost without the shelf life constraint	Order cost with the shelf life constraint
Lot for lot	73,206	73,206
EOQ	35,299	35,299
POQ	59,526	59,526
Modified EOQ	45,846	45,846
Least unit cost	45,846	45,846
Least total cost	30,726	39,846
Part period balancing	31,926	44,910
Wagner-Whitin	41,286	50,436
Silver-Meal	39,726	45,846
Multi-echelon optimization	36,846	35,578

When a comparison is made according to the order costs, the order cost of lot for lot in each period is much higher than the other methods, as expected. Following it, the POQ method is observed to be the method with the highest order cost. The case in which the order cost was the lowest was with the least unit cost method when the shelf life was disregarded, while the cost obtained as a result of optimization when the shelf life was included was calculated as the lowest value as seen in Figure 4 and Table 4.

Figure 4. A comparison of the lot-sizing methods according to the order costs

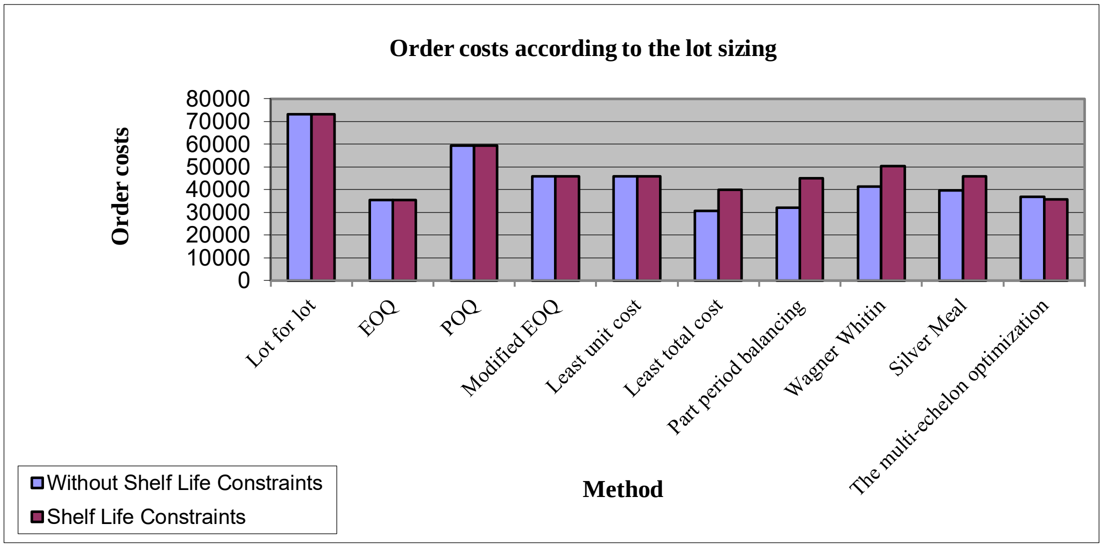
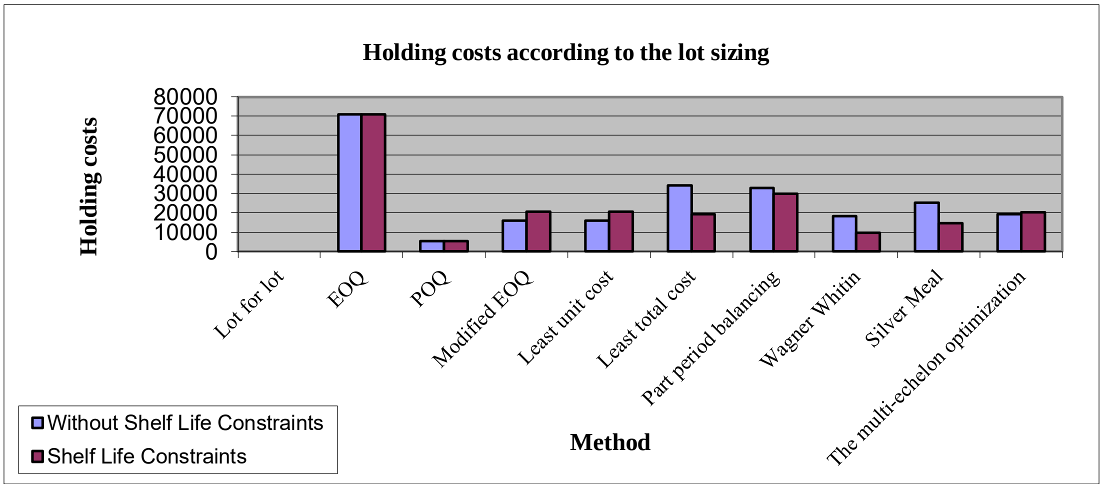


Table 5. A comparison of the lot-sizing methods according to the holding costs

	Holding cost	
Method	**without the shelf life constraint**	**With the shelf life constraint**
Lot for lot	0	0
EOQ	70,746	70,746
POQ	5,521	5,521
Modified EOQ	16,055	20,640
Least unit cost	16,055	20,640
Least total cost	34,287	19,379
Part period balancing	32,840	30,007
Wagner-Whitin	18,487	9,896
Silver-Meal	25,387	14,563
Multi-echelon optimization	19,368	20,286

In the examination according to the holding cost, the cost-effective result was obtained with the method of lot for lot as the holding cost would be 0 (zero) when the requirement of each period was met within that period. The EOQ method yielded very high cost values due to the high end of period stocks in period planning and the large quantity of the finished-/semi-finished products available at the end of the planning horizon. The POQ and Wagner-Whitin methods are the other methods with low holding costs (as presented in Figure 5 and Table 5).

Figure 5. A comparison of the lot-sizing methods according to the holding costs



5. Conclusion

In this study, the lot sizes are determined with and without shelf life constraints for three most produced types of gum for a factory with the real data from the same factory. Therefore, ten different lot-sizing methods were compared in terms of the number of orders, order cost, total cost, and holding cost, and the method which minimized the total cost for the three selected products was determined in an applied fashion. The first finding among the findings in the light of the data obtained from the application is that the requirement for ensuring the agreement between the echelons is of importance when computing the sub-echelon requirements from the end product. In this way, continuing with the next echelon only after lot sizing starting from the first echelon can yield significant results in those methods which do not take all echelons into account collectively.

When a comparison was made according to the number of orders, as seen in the Table 3 and Figure 3, the method offering the lowest cost under the condition without the shelf life constraint was the method of part period balancing. On the other hand, the lowest cost under the condition with the shelf life constraint was obtained by the method of multi-echelon optimization.

When the lot-sizing methods were compared according to the order costs (as seen in Table 4 and Figure 4), the least total cost method provided the lowest cost under the condition without the shelf life constraint. Under the condition with the shelf life constraint, the EOQ was the method with the lowest cost.

When the results were considered according to the holding costs, the cost-effective result for the cases both with and without shelf life constraints was obtained with the method of lot for lot (as seen Table 5 and Figure 5). The EOQ method yielded very high cost values due to the high end of period stocks in the period planning and the large quantity of finished-/semi-finished products available at the end of the planning horizon. The POQ and Wagner-Whitin methods are the other methods with low holding costs. When the lot-sizing methods were compared according to their total costs, the multi-echelon optimization method offered the lowest cost under the conditions with and without shelf life constraints.

Another important result obtained is that the methods considered to yield the cost-effective result do not have exact feasibility for all firms and that additional arrangements might be required depending on the features of a firm. As a result, if the firm takes the order quantity not as much as the net requirements calculated for each period, but the values calculated using the lot size techniques that form the basis of this study, it will have an order policy with a lower cost. Another essential result is that the single-echelon calculations are intended to optimize some of the system, but not the entire system, and that the Wagner-Whitin algorithm, considered to yield the cost-effective result, did not yield the cost-effective result in a multi-echelon system whereby the products interacted. The study, presented by the help of a multi-echelon and multi-item linear programming algorithm which was developed considering the method proposed by Steinberg and Napier and in which perishing of the products was not allowed, can be shown as an example on this subject. Likewise, capacitated multi-echelon lot-sizing methods can be examined in the studies by Billington et al. (1983) and, Tempelmeier and Helber (1994).

In this study, the assumption that the shelf life is fixed and that the product does not lose value until the end of this period may not apply to every type of product. Thus, it is possible to develop it in agreement with the systems whereby the perishing rate or the shelf life is not fixed and the product loses value within the period when it remains in stock. Another aspect likely to be developed is the case in which the demand is not deterministic but stochastic. As a future study, it can be suggested to develop applications in these areas with intelligent and heuristic approaches.

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