Inventory as an Enterprise Positioning Strategy Using Fuzzy Logic

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Abstract

This work presents a theoretical extension to the inventory model EOQ with and without production, representing all variables as crisp and fuzzy quantities. The model is compared against the classical EOQ model with and without production. In this comparison, crisp and fuzzy data were used, and the results and conclusions were contrasted. These representation and reasoning mechanisms enables strategic design for operational decision making in the enterprise, which will make the enterprise a world class company.

Key Words: *Fuzzy Logic, Inventory, Decision Making, Crisp.*

Introduction

In the production dynamics of a company, the production and inventory management requires flawless strategic planning (González et al. 2002), (González et al. 2010), (González et al. 2011), (González et al. 2013). This planning must include product demand forecast, optimal use of the plant capacity, and optimization of human resources, manufacture and acquisition times and amounts.

Kaufmann A. and Gil Aluja J. (Kaufmann and Gil, 1986) define the production process as the central nucleus of the production process. The enterprise's activity revolves around this nucleus, demanding raw material and finished products supply. That makes necessary the design of an efficient material delivery program. Otherwise, the plant may become inactive due to the lack of raw material. This situation leads to high cost levels, produced by operating the plant at levels below its capacity.

Managers keep raw material and finished product stocks, which represent static assets. These assets could be used in other productive activities. This situation arise for the following reasons:

- Productive activity makes impossible to maintain a given stock level.
- Uncertainty in future demand leads to keeping a minimum inventory level.
- Speculations arise when a sudden increase in prices is expected, or there is a high possibility of sales increase in the future.

Inventory control (Narasimhan et. al., 1996) is a critical aspect of successful management. When keeping inventories is costly, companies cannot have high stock volumes. To minimize the stocks, the company must execute a flawless planning to match the offer and demand levels, seeking the condition where the stock amount be minimal. Inventory is an amount of stored materials to be used in production or to satisfy the consumers demand (Schroeder, 1993). Basic decisions to be made in stock management, among others, are:

- When to order?
- How much to order?

To answer these questions we need to know the behaviour of the company's expected demand for the period of time under analysis, annual stock cost **(h)**, generally a percentage of the item cost, the item cost (C), and service costs (S).

Stock management is one of the most important managerial functions, since it demands assets and if not performed properly, it can delay delivery of products to consumers. Optimal stock management has impact on production, marketing, and finance. The operational components found in stock management are: Financial. Seeks to keep low inventory levels, to avoid excessive stock levels and maintain low costs. Marketing. Seeks to keep high inventory levels, to assure supply and sales. Operating. Seeks to keep adequate stock levels to guarantee an efficient production and homogeneous usage levels.

A company needs strong stock management systems to balance the above requirements, whose ideal stock levels conflict. This leads to seeking an optimal stock level, which allows the company to satisfy the market needs using the least possible amount of financial resources.

In a stock system, there exists uncertainty in the offer-demand behaviour, and in the time required to complete the process until products reach consumers. The problem addressed in this paper is the determination of how much to order to maintain a minimum stock level and still be able to face an uncertain demand. We also determine the time to order, when the company is or is not in production.

This paper is organized as follows: Section1 provides an introduction; Section 2 provides background knowledge on stock costs; Section 3 explains demand behaviour; Section 4 and 5 present the classical EOQ model with ad without production, respectively; Section 6 presents a case analysis; Section 7 presents the results; Sections 8 and 9 present the conclusions and recommendations.

Materials and Mehods

Stock Costs

The structure of inventory (Harris, 1915), (Bellman, R. E., Zadeh, L.A., 1979), (De S.K.,et al, 2008), (De S.K.,et al, 2003), (De S.K., 2013) costs et a includes the following types of costs: Item cost. The cost of purchasing and/or producing the stock items. Generally expressed as the unit cost times the stock capacity. Ordering cost, preparation, or waste. This cost is related to the purchase of a group or lot of items. This cost does not depend on the number of items. Inventory cost. This cost is related with storing items for a period of time. This cost is usually expressed as a percentage of the item value per unit of time.

Inventory costs normally have three components: Equity cost. This cost arises when items are stored and equity is not available for other purposes. This cost represents the cost of not performing other investments. Storage cost. This cost includes components that vary with space, insurance, and taxes. Obsolescence, damage, and waste cost. These costs are assigned to items that age or expire, the higher the risk to become unusable, the greater the cost rate. The costs of items that expire are added to aging costs. For instance, in some grocery items, the loss costs include stolen items and damage related to maintaining them in stock. Out of stock cost. This kind of cost reflects the consequences of running out of stock for each product in the inventory. It includes raw materials, finished products, etc. The lack of an item brings causes the loss of an opportunity to produce or sell a product.

Demand Behavior

Future demand in an enterprise can be classified according to what we know about it (Hariga, M.A., 1996), (Kumar, R.S., et al., 2012), (Kaufmann and Gil, 1986), (González and Flores, 2002): When the company knows exactly the demand's behavior with time. This fact represents deterministic or certain demand. When the company does not know exactly how demand behaves. This situation represents a probabilistic or stochastic behavior. When the company does not know the future levels of demand, but takes advantage of a set of experts' knowledge, expressed with uncertainty, and the reasoning framework to be used in fuzzy logic.

Classical Economic Order Quantity (EOQ) – No Production

F.W. Harris developed this methodology in 1915 (Harris, 1915), and it is still in use for inventory management when demand is an independent variable. The basic assumptions of the model are: The demand rate is known and constant along time. Delivery time is constant and zero. Since demand and delivery are instantaneous, there is no stocking. Materials are bought or produced in groups or lots, and place in stock. Unit cost per item is constant and there is no discount for bulk sales. The cost to place an order is k monetary units. An item unit cost is c. The unit storage cost is h. There is no interaction between products. According to these assumptions, stock behaves as shown in Fig.1.

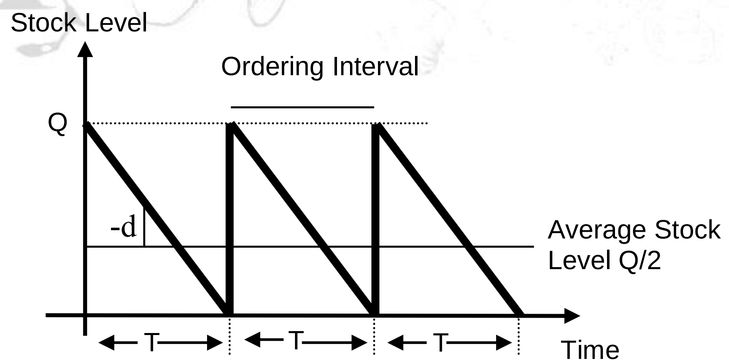

Figure 1: EOQ Model

Where Q is the ordering amount (in number of units), d is demand (in number of units/time), K is the fixed cost, c is the cost per unit ($/unit), and h is the storage cost per unit = i %(c). Figure 2 shows the behaviour of cost; as Q increases, the purchasing cost decreases, since we place less orders per year. At the same time, the stocking cost increases, since the stock level increases. Therefore, purchasing and stocking costs compensate, one decreases while the other one increases. To determine the value of Q, that minimizes CP(Q) we compute the partial derivative of CP(Q) and solve for Q when it is zero. The cost per period is given by Equation (1).

$$CT(Q) = k + cQ + h\left(\frac{Q}{2}\right)T \qquad (1)$$

The optimal cost is given by Equation (2).

$$CP(Q) = \lim_{n\to\infty}\left[\frac{n\,CT(Q)}{n\,T}\right] = \frac{CT(Q)}{T} = \frac{k+cQ+h\left(\frac{Q}{2}\right)T}{T} = \frac{k\,d}{Q} + c\,d + \frac{h\,Q}{2} \qquad (2)$$

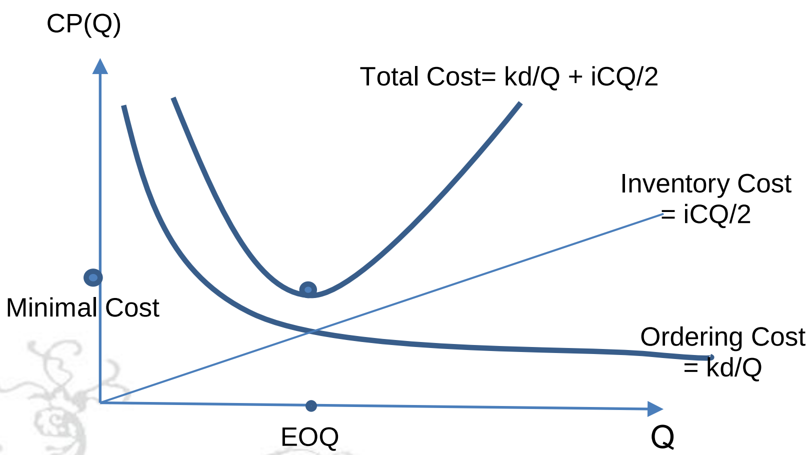

Fig. 2. Cost Behavior

But

$$T = \frac{Q}{d} \qquad (3)$$

$$\frac{\partial\, CP(Q)}{\partial\, q} = 0 = -\frac{k\,d}{Q^2} + \frac{h}{2} = 0$$

$$\frac{k\,d}{Q^2} = \frac{h}{2}$$

$$Q^2 = \frac{2\,k\,d}{h}$$

Assuming $C_p = k$ and $C_h = h$, we obtain Equation (4).

$$Q = \sqrt{\frac{2\,k\,d}{h}} = \sqrt{\frac{2\,C_p d}{C_h}} \qquad (4)$$

Q represents the ordering size that minimizes the stock average operation cost. Q is generally computed per year, but any time unit can be used. To determine the time required for the stock to reach zero, we use Equation (5).

$$T = \frac{Q}{d} = \sqrt{\frac{2\,C_p}{C_h d}} = \frac{1}{N} \qquad (5)$$

The stock optimal average cost can be computed using Equation (6).

$$CP(Q) = \frac{kd}{Q} + cd + \left(\frac{hQ}{2}\right) \qquad (6)$$

Classical Economic Order Quantity (EOQ) – with Production

In normal operation, the demand and consumption of produced units occur at a constant rate (González et al., 2002). Let us assume the production rate is greater than the demand rate. With any other assumption, stock will not accumulate and there will be a lack of products. Let p be the production rate and d the demand rate (both considered constant). The objective function is a function of the total cost (Eq. (7)).

$$CIT = Ordering\ Cost\ + \text{Maintenance}\ Cost \qquad (7)$$

The ordering cost is given by Equation (8).

$$\mathrm{C_p}\left[\frac{\mathrm{d}}{\mathrm{Q}}\right] \qquad (8)$$

The interpretation of the ordering cost while producing is known as start-up. This cost includes man-hours worked, material, and production loss cost (incurred while getting the production system ready for operation). It is a fixed cost for each production lot, independent of the number of items being produced. Start-up downtimes are integrated to the production plan development costs for each item, ordering formulation, all paperwork needed to prepare machinery and equipment, and the order flow control along the company's process. Maintenance cost is the unit cost to keep equipment running, times the mean stock level.

Since the production of the ordered amount (Q) takes place over a period of time defined by the production rate (p) and the parts enter the stock at the production rate, given a consumption rate, we obtain the inventory behavior shown in Figure 3. The maximum and mean inventory levels are a function of the lot size, de production rate (p) and the demand rate (d) (Guiffinda et al., 2010). To determine the mean inventory level (I_p), since items are being received and consumed simultaneously, we first compute the time (t_p) required to produce the amount *(Q)*. See Equation (9).

$$t_p = \frac{Q}{p} \qquad (9)$$

Where t_p is the time required to produce the ordered amount Q, given the supply rate p. The maximum Inventory level is given by Equation (10).

$$\mathrm{I_{max}} = \mathrm{t_p}(\mathrm{p}-\mathrm{d}) = (\mathrm{p}-\mathrm{d})\left(\frac{\mathrm{Q}}{\mathrm{p}}\right) = \mathrm{Q}\left(1-\frac{\mathrm{d}}{\mathrm{p}}\right) \qquad (10)$$

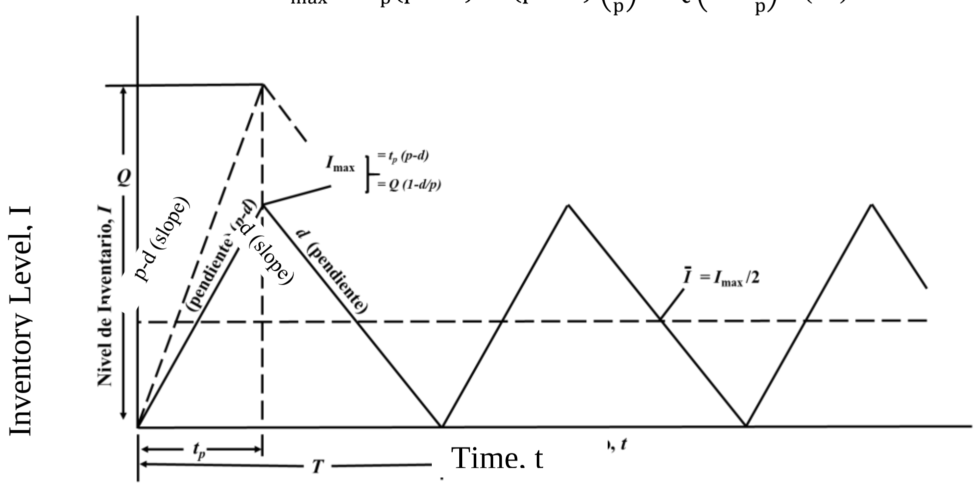

Fig. 3. Inventory Model with Production

Where (p-d) is the stocking rate and t_p is the replenishing time (we assume p>d). Between replenishing times, stock decreases at a demand rate d.

To compute the total inventory cost, we need to express the maximum stock level in terms of the ordering amount (Gallagher et. al., 1982). The mean inventory level is given by Equation (11).

$$I_p = \frac{t_p(p-d)}{2} = \frac{I_{max}}{2} \quad (11)$$

Substituting Eq. (9) in Eq. (11), we obtain Equation (12).

$$I_p = \left[\frac{Q}{2}\right]\left[1 - \frac{d}{p}\right] \quad (12)$$

The annual maintenance cost (CM_a) and the total cost (C_T) are given by Equations (13) and (14), respectively.

$$CM_a = C_h\left(\frac{Q}{2}\right)\left[1 - \frac{d}{p}\right] \quad (13)$$

$$C_T = C_p\left(\frac{d}{Q}\right) + C_h\left(\frac{Q}{2}\right)\left(1 - \frac{d}{p}\right) \quad (14)$$

Since the ordering amount is given by Equation (15), the total cost can be expressed as in Equation (16).

$$Q^* = \sqrt{\frac{2C_p d}{C_h\left[1 - \frac{d}{p}\right]}} \quad (15)$$

$$C_T^* = \sqrt{2C_p C_h d\left(1 - \frac{d}{p}\right)} \quad (16)$$

Finally, the optimal production lot size and optimal time between lots are given by Equations (17) and (18), respectively.

$$N^* = \frac{d}{Q^*} \quad (17)$$

$$T^* = \frac{1}{N^*} = \frac{Q^*}{d} \quad (18)$$

Case Analysis

To illustrate the application of the (EOQ) model, with and without production, both under certainty and uncertainty, we will use the case described in this section. The company El Zapato Dorado, is a world-class company that ships shoes worldwide from León, Guanajuato, Mexico. According to its records, the total stock is 10,000 pairs of shoes. The mean cost per pair is $12.00, so the total inventory cost is $1,200,000.00. The equity cost is estimated as an annual rate of 5%, taxes, insurance, damages, wastes, and storage management costs are also 5%.

The most requested shoes in the market are type 1. A marketing research and statistics indicate that last year 10 orders of 1,000 pairs were placed per period (5 weeks), at a cost of $20.00 per pair. The manufacturer guarantees that each order is delivered in 3 days, which has been accomplished so far. The average demand is 200 pairs per week. The company takes 30 minutes to process an order. The cost per order is $16.00 per hour. Other costs include office supplies, mailing, telephone, clerical work, and transportation amount to $1.00 per order. Given this, the total cost of ordering is $17.00.

The company faces the choice of keeping a small stock and order frequently, or keep a large stock and order infrequently. The first choice may produce excessive ordering costs, while the second one would imply a higher stocking cost. So, we need to obtain an optimal ordering amount, minimizing stocking costs and still satisfying all market requirements.

As Q grows, the stock management costs grow. This implies that the annual number of orders decreases non-linearly, tending to zero, asymptotically. In the model that includes production, we assume the company installs a new production plant next to the main storage. Let us assume the plant's capacity (production rate) p=15,000 pairs per year, C_h = $2.00, and C_p = $ 9.00.

Fuzzy EOQ – No Production

To analyze the system under uncertainty, we use a fuzzy logic model, using triangular fuzzy numbers. (kao, C., Hsu, W. K., 2002), (Kazemi, N. et al., 2015), (Mahata G. et al., 2007), (Mahata G. et al., 2011), Mahata G. et al., 2013).

Following the information provided by a panel of experts, using the Delphi, we have: $\tilde{d}$= (9 500, 10 000, 10 500), $\tilde{C}_p$ = (8.5, 9, 9.5), and $\tilde{C}_h$= (1.5, 2, 2.5). The analysis is performed using a 11-value scale for fuzzy linguistic terms. To each $\propto$-cut $[0 \le \propto_k \le 1]$, corresponds a confidence interval $[r_k^{\propto}, s_k^{\propto}]$ that can be expressed as a function of $\propto_k$ (see Equation (19)).

$$[r_k^{\propto}, s_k^{\propto}] = [r + (m - r) \propto_k, s - (s - m) \propto_k] \quad (19)$$

For demand ($\tilde{d}$), the confidence interval is expressed in Equation (20), which is evaluated for the different $\propto$-cuts as in Table 1.

$$[r_k^{\propto}, s_k^{\propto}] = [9500 + 500 \propto_k, 10\,500 - 500 \propto_k] \quad (20)$$

Table 1. Demand Confidence Intervals for different $\propto$-cuts

$\propto_k$	r_k	s_k
0	9500	10500
0.1	9550	10450
0.2	9600	10400
0.3	9650	10350
0.4	9700	10300
0.5	9750	10250
0.6	9800	10200
0.7	9850	10150
0.8	9900	10100
0.9	9950	10050
1	10000	10000

For $\tilde{C}_p$ = (8.5, 9, 9.5), the confidence interval is expressed in Equation (21), which is evaluated for the different $\propto$-cuts as in Table 2.

$$[r_k^{\propto}, s_k^{\propto}] = [8.5 + 0.5 \propto_k, 9.5 - 0.5 \propto_k] \qquad (21)$$

Table 2. Ordering Cost Confidence Intervals for different ∝-cuts

$\propto_k$	r_k	s_k
0	8.5	9.5
0.1	8.55	9.45
0.2	8.6	9.4
0.3	8.65	9.35
0.4	8.7	9.3
0.5	8.75	9.25
0.6	8.8	9.2
0.7	8.85	9.15
0.8	8.9	9.1
0.9	8.95	9.5
1	9	9

For $\tilde{C}_h$ = (1.5, 2, 2.5), the confidence interval is expressed in Equation (22), which is evaluated for the different ∝-cuts as in Table 3.

$$[r_k^{\propto}, s_k^{\propto}] = [1.5 + 0.5 \propto_k, 2.5 - 0.5 \propto_k] \qquad (22)$$

Table 3. $\tilde{C}_h$ Cost Confidence Intervals for different ∝-cuts

$\propto_k$	r_k	s_k
0	1.5	2.5
0.1	1.55	2.45
0.2	1.6	2.4
0.3	1.65	2.35
0.4	1.7	2.3
0.5	1.75	2.25
0.6	1.8	2.20
0.7	1.85	2.15
0.8	1.9	2.1
0.9	1.95	2.05
1	2	2

The ordering quantity (**Q**) is determined by Equation (23):

$$\tilde{Q} = \sqrt{\frac{2\tilde{d}\tilde{C}_p}{\tilde{C}_h}} \qquad (23)$$

$$\tilde{Q} = (254, 300, 364)$$

The Total Annual Cost ($\widetilde{CIT}$) is determined by Equation (24):

$$\widetilde{CIT} = \sqrt{2\tilde{C}_p\tilde{C}_h\tilde{d}} \qquad (24)$$

$$\widetilde{CIT} = (492.18, 600, 706.22) \approx (492, 600, 706)$$

The Optimal Order Size or Number ($\tilde{N}$) is determined by Equation (25):

$$\tilde{N} = \frac{\tilde{d}}{\tilde{Q}} \qquad (25)$$

$$\tilde{N} = (26, 33.33, 41.33)$$

The Ordering Pertiod ($\tilde{T}$), is determined by Equation (26):

$$\tilde{T} = \frac{1}{\tilde{N}} \qquad (26)$$

$$\tilde{T} = (0.0241, 0.030, 0.0384)$$

Fuzzy EOQ Analysis – with Production

According to (Mahata C. G., 2015), (Kaufman A.,and Gil Aluja J. et al., 1986, 1994), following the opinion of a set of experts using the Delphi method, the behaviour of the involved variables was estimated as described below.

$$\tilde{d} = (9\,500, 10\,000, 10\,500) \qquad (27)$$

$$\widetilde{C_p} = (8.5, 9, 9.5)$$

$$\widetilde{C_h} = (1.5, 2, 2.5)$$

$$\tilde{p} = (14\,500, 15\,000, 15\,500)$$

The fuzzy ordering amount ($\tilde{Q}$) is given by Equation (28)

$$\tilde{Q} = \sqrt{\frac{2\widetilde{C_p}\,\tilde{d}}{\widetilde{C_h}\left[1 - \frac{\tilde{d}}{\tilde{p}}\right]}} = \sqrt{\frac{2(8.5, 9, 9.5)(9500, 10000,10500}{(1.5, 2, 2.5)\left[1 - \frac{(9500, 10000,10500)}{(14500,15000,15500)}\right]}}$$

$$\tilde{Q} = (409, 520, 694) \qquad (28)$$

The Total Annual Cost ($\widetilde{CIT}$) is determined by Equation (29):

$$\widetilde{CIT} = \sqrt{2\widetilde{C_p}\,\widetilde{C_h}\tilde{d}\left(1 - \frac{\tilde{d}}{\tilde{p}}\right)} \qquad (29)$$

$$\widetilde{CIT} = (258.52, 346.44, 539.39)$$

The optimal number of lots of size (N) is determined by Equation (30):

$$\tilde{N} = \frac{\tilde{d}}{\tilde{Q}} = \frac{(9\,500,10\,000,10500)}{(409,520,694)} \qquad (30)$$

$$\tilde{N} = (13.68, 19.23, 25.67)$$

The optimal Ordering Pertiod ($\tilde{T}$), is determined by Equation (31):

$$\tilde{T} = \frac{1}{\tilde{N}} = \frac{\tilde{Q}}{\tilde{d}} = \frac{(409,520,694)}{(9\,500,10\,000,10\,500)} \qquad (31)$$

$$\tilde{T} = (0.038, 0.052, 0.073) \text{ years}$$

which expressed in days would be (12.25, 18.2, 25.55).

Results

Table 4 compares the results of the EOQ model without production in the classical and the fuzzy versions.

Table 4. Results of the classical and fuzzy EOQ models without production

Classical EOQ	Fuzzy EOQ
Q = 300 units	$\tilde{Q}$ = (254, **300**, 364)
CIT = $ 600.00	$\widetilde{CIT}$ = (492.18, 600, 706.22) ≈ (492, **600**, 706)
N = 33.33 ≈ 33 orders per year	$\tilde{N}$ = (26, 33.33, 41.33)
T = 0.030 per year	$\tilde{T}$= (0.0241, **0.030**, 0.0384)

Table 5 compares the results of the EOQ model with production in the classical and the fuzzy versions.

Table 5. Results of the classical and fuzzy EOQ models with production

Classical EOQ with Production	Fuzzy EOQ with Production
Q = 522 units	$\tilde{Q} = (409, \mathbf{520}, 694)$
CIT = $ 346.41	$\widetilde{CIT}$ = (258.52, **346.44**, 539.39)
N = 19.14 orders per year	$\tilde{N}$ = (13.68, **19.23**, 25.67)
T = 0.052 per year = 18.2 days	$\tilde{T}$ = (0.038, **0.052**, 0.073)

Conclusions

From the analysis performed, we conclude that it is necessary to increase the used market capability, taking into account a variation on the demand level of (9,500, 10,000, 10,500) pairs of shoes and the variation of costs (fixed and inventory management unit cost) $\tilde{C}_p$ = (8.5, 9, 9.5) and $\tilde{C}_h$= (1.5, 2, 2.5). For a company with the adequate conditions to produce directly the demand requirements, or seek external providers to satisfy the needs and turn into a marketer of products that designs and outsource. According to the obtained results, it is convenient for the company El Zapato Dorado to adopt the EOQ system with production. This conclusion is derived from the fact that when it operates with production, the annual operation cost (CIT) almost doubles for non-production conditions. Similarly, although the inventory level with production almost doubles the non-production scenario, it allows increasing the sales level and starting new markets. These new markets will allow the company to place that stock and increase its profit level.

Recommendations

Taking the conclusions as reference, we recommend to include fuzzy logic to the inventory operation analysis. We recommend the deployment of the EOQ model with production. This model will provide a competitive advantage in decision making when used under uncertainty. This is a consequence from the fact that classical theory hides information that the fuzzy theory reveals. Using this approach, we include higher quality information to the analysis scenario, which allows us to direct the strategic planning of the company, which leads to better financial results and an advantage in the market position for the company.

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