Sensitivity analysis applied to a collaborative inventory model

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Abstract. When inventory models are applied independently, they are far from reality because in a supply chain all the elements and process are connected, for which collaborative models have been proposed that represent real behavior between them.

The proposal and development of collaborative models that relate the buyer and supplier aim to reduce the costs of the supply chain and increase the profitability of the participating companies. To apply collaborative models, it is necessary to develop the exchange of information and formulation of plans that allow to reduce costs and obtain benefits for all the parties involved.

The objective of this paper is to show, through a sensitivity analysis, the impact of the optimal quantity to order and produce on the cost of inventories, the analysis is carried out for the EPQ model and a collaborative inventory model to identify the optimal quantity to order and produce that minimizes costs in the supply chain.

In addition to identifying the optimal quantities to order and produce, it is necessary to determine how profitable the investment in the inventory is, which can be calculated with the GMROI, this being an important indicator to check performance and identify areas where profit margins can be increased.

Keywords: sensitivity, inventories, collaborative models, GMROI.

1 Introduction

Inventories represent one of the most important investments of companies in relation to the rest of their assets. The objective of the inventory is to absorb the differences that arise between the supply and demand of an item, to avoid shortages [1].

Inventory control focuses on the tradeoff that arises when a decision-maker aims to meet customer demand while maximizing the profitability of operations [2]. Therefore, every organization requires strict control of the inventory item because it represents one of the most important concepts of the economic entity, which must be reflected in the company's financial statements [3].

Inventory is a fundamental element within the management of working capital for any company, it often constitutes 15% of the value of the assets and in the case of a retailer, it could represent more than 25% of the assets [2]. Because the inventory occupies a significant percentage that impacts the profitability of the company, any procedure or technique that allows reducing its costs can contribute positively to the rate of return [3]. A tool that serves as support to evaluate responses to the techniques or models applied for inventory management is sensitivity analysis. In this paper, an evaluation is carried out through a sensitivity analysis between the EPQ model and a collaborative inventory model to identify the optimal quantity to order and produce that generates the lowest cost in the supply chain.

2. Literature review

A sensitivity analysis is an analytical process that studies the changes generated in the optimal solution from the changes in the variables or parameters involved, generating a dynamic environment. Sensitivity analysis applied to an inventory model aims, to identify the variable that produces the greatest change in the result.

Cao [4] analyze the effect of changes between estimated and actual values in printer inventory systems with stochastic demand, the results of the sensitivity analysis allowed him to know the behavior of the system to make operational decisions.

Khanra [5] (2014) perform a sensitivity analysis of the classical newsboy model, established a lower bound of cost deviation for unimodal demand distributions, also compare it with the EOQ model, and observed that cost deviation increases with the ratio of demand. Malik [6] proposed an inventory model and through a sensitivity analysis performs the analysis of the model, presents seven scenarios by changing values in the variables of demand, the sales revenue cost, and the purchasing cost per unit item, and analyzes the impact of change the variables in the ordering cycle, the total profit per unit time of the inventory system and maximum inventory level.

Basri [7] presents a case study of a hospital for which it calculates the optimal amount of drugs to order, using the EOQ model, proposes a sensitivity analysis changing the cost of ordering and maintaining inventory to obtain the average inventory level. Through sensitivity analysis, she explains various scenarios that facilitate decision-making to reduce overstocking.

Shinn [8] analyzed a distributor inventory model in a two-stage supply chain composed of the supplier, the distributor, and the final customer, and performed a sensitivity analysis showing the effect of the credit period on the distributor lot size and the selling price.

Through the review of the literature, it has been identified that sensitivity analysis is a tool that is continuously applied to evaluate, analyze, and compare different scenarios to support decision-making. This work contributes to the literature by developing a sensitivity analysis to deterministic inventory models, showing the different scenarios that occur when changing the optimal quantity to order and the impact on the cost of the inventory of the buyer and supplier.

3 Classic inventory models

Inventory theory has its roots in the Economic Order Quantity model (EOQ) proposed by Harris in 1913 and Wilson in 1934, this model was the pioneer and has been the basis for the development of other variants of the model. The EOQ model remains an important tool for companies that want to minimize their inventory costs by finding a balance between the number of orders per year and the annual maintenance cost [9]. The basic concept of this model is to create a balance between ordering costs and storage costs. This model operates with the assumptions of constant and deterministic demand (D), immediate replenishment, and constant costs. The demand can be determined from forecasts or by an estimate from the analysis of historical data [10].

The EOQ model without missing parts focuses on the calculation of the quantity to order (Q) given by equation (1), the annual cost of inventory K(Q) described by equation (2) in which the annual cost of ordering (A) and holding inventory (h) are balanced.

$$Q = \sqrt{\frac{2AD}{h}} \tag{1}$$

$$K(Q) = cD + \frac{AD}{Q} + \frac{hQ}{2} \tag{2}$$

From the EOQ model, the Economic Quantity to Produce (EPQ) model arises. This is a mathematical model for inventory control that aims to determine the optimal quantities to produce to minimize total manufacturing costs.

The EPQ mathematical without missing parts model has assumptions that all the articles produced are of perfect quality, a constant production in a certain period to satisfy the demand. The model is based on assumptions of constant and deterministic demand (D), production rate (P), and production size (Q*) constant. For this model, there is a cost for preparing a production run (A) and a cost for holding inventory (h). The optimal quantity of the batch to be produced is described by equation (3) and the total inventory cost is calculated by equation (4).

$$Q^* = \sqrt{\frac{2AD}{h\left(1-\frac{D}{P}\right)}} \tag{3}$$

$$K(Q) = cD + \frac{AD}{Q} + h\frac{Q\left(1-\frac{D}{P}\right)}{2} \tag{4}$$

In the EOQ and EPQ inventory without missing parts models, sensitivity analysis can be carried out to analyze the changes in the economic quantity to be ordered when the demand (D), the cost to hold (h), and the cost to prepare (A) vary. Likewise, the change in K(Q) related to any change in the variables involved in its calculation can be analyzed to determine how the variables influence the cost of the inventory.

Sensitivity analysis applied to a variable is used with the purpose of identifying the variable that produces the greatest change in an outcome. A simple way to perform a sensitivity analysis is to assign different values to a variable by building a table that will have different results associated with it. Sensitivity analysis is a tool that facilitates decision-making as it allows various scenarios to be visualized that depend on the behavior of one or several variables.

3.1 Collaborative models

Collaborative activities in a supply chain depend on relationships between suppliers, manufacturers, customers, and other stakeholders. Collaboration relates to two or more independent companies that work together, to carry out operations that generate greater benefits than those achieved individually. Several authors have modified traditional inventory models to make them more realistic, as all elements are interconnected [11]. Bookbinder and Heath (1988) developed the Distribution Requirements Planning (DRP) concept [12]. The objective of the DRP model is to minimize the inventory and cost in the distribution system for a certain level of service and forecast demand through the planning of inventory levels and replenishments. This requires reliable and timely information on sales, inventory, and forecast of inventory locations in the distribution network [13].

The DRP approach is time-phased replenishment. The inventory status is reviewed at each phase, and new shipment plans are generated periodically, as inventory is planned throughout the supply chain. Advantages of DRP include reduced inventory, better customer service, and compatibility with other systems within the supply chain [14]. The Collaborative Planning, Forecasting and Replenishment (CPFR) model, a tool registered in 1998, aims to reduce inventories and expenses without affecting customer service [15]. The CPFR model has been implemented in the companies Wal-Mart, Heineken USA, and Coca-Cola FEMSA, improving the accuracy of forecasting demand, order, and sales, generating lower acquisition costs, smaller inventories, shorter cycle times, and faster response to market [16].

Vendor Managed Inventory (VMI) is a collaborative model used to monitor customer inventory replenishment, linking the different planning processes of each partner. Each partner must share their vision of the demand, requirements, and limitations to establish common objectives for each product. By implementing the VMI model, the supplier knows the customer's demand, resulting in a sales forecasting method and an effective inventory distribution [17].

A collaborative inventory model proposal is the one developed by Velásquez (2013) where he relates the behavior of the buyer and supplier inventory considering the total cost in the supply chain. The sum of the buyer and supplier costs is found in equation (5) and for the calculation of the optimal order quantity that minimizes the cost as a whole, it is obtained by equation (6).

$$K(\mathrm{Q}) = A_b \frac{\mathrm{D}}{\mathrm{Q}} + h_b \frac{Q}{2} + A_s \frac{\mathrm{D}}{\mathrm{Q}} + h_s \frac{Q\left(\frac{D}{P}\right)}{2} \tag{5}$$

$$\mathrm{Q}^* = \sqrt{\frac{2(\mathrm{A_b}+\mathrm{A}_s)\mathrm{D}}{\mathrm{h}_b+\mathrm{h}_s\left(\mathrm{D}-\frac{\mathrm{D}}{\mathrm{P}}\right)}} \tag{6}$$

In which A_b denotes the annual cost of ordering for the buyer, A_s is the cost for preparing a production run for the supplier, h_b is the cost for holding inventory for the buyer, and h_s is the cost for holding inventory for the supplier. Equation (7) represents the total inventory costs for the supplier and equation (8) to calculate the production lot size that minimizes the associated costs for the supplier.

$$K_p(Q) = A_p \frac{D}{Q} + h_p \frac{Q\left(\frac{D}{P}\right)}{2} \quad (7)$$

$$Q^* = \sqrt{\frac{2A_P\text{D}}{h_p\left(\text{D}-\frac{\text{D}}{\text{P}}\right)}} \quad (8)$$

Through a collaborative inventory model between buyer and supplier, the costs of the supply chain can be minimized, which is why it is important that the buyer and supplier can establish negotiations in terms of cooperation and collaboration [18].

3.2 Gross margin return on inventory investment

Profitability indicators are those financial indices that serve to measure the effectiveness of the company's management and assess how quickly profits can be generated compared to the expenses generated over a period. Profitability is measured by establishing relationships between the income statement and the balance sheet a key indicator that allows for evaluating the profitability of inventories is Gross margin return on inventory investment (GMROI), which is an indicator that allows knowing the capacity of a company to turn its inventory into profits and is calculated by dividing the gross margin by the average cost of its inventory in each period.

The GMROI can be used as a tool that indicates the amount of gross margin that is returned for each monetary unit invested in the inventory, at the same time it shows the degree of inventory turnover and the return on investment in it, it is expressed as a percentage or monetary multiples, the expression to calculate it is shown in equation (9).

$$\text{GMROI} = \frac{\text{Annual sales}}{\text{Average inventory cost}} * \text{Gross margin\%} \quad (9)$$

A GMROI value equal to 1 is equivalent to saying that for each monetary unit invested in the inventory, the return in a year is one monetary unit, which indicates that no profitability was generated in that year. A GMROI value greater than 1 indicates that profitability was generated, while a value less than 1 indicates that there were losses.

A product can have a high margin, but a low sales volume, so the gross margin depends on the total stock in the inventory and its rotation and is calculated with the expression (10). To optimize GMROI, it is necessary to increase inventory turnover, decrease inventory levels, and improve gross margins by raising prices or improving supplier relationships to obtain discounts. The productivity of a company indicates the return on investments and depends on factors such as gross margin, inventory turnover, growth rate, company size, management efficiency, and macroeconomic factors [1].

$$\% \text{ Gross margin} = \frac{\text{Sales} - \text{Costs of sales}}{\text{Sales}} \quad (10)$$

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4 Problem Statement

Classical inventory models are the data to apply the model is known with accuracy, but they are usually estimated or approximate data that are considered ideal, without considering the variations and effects on inventory costs and the quantities to order or produce. Therefore, it is necessary to carry out sensitivity analyses to models to generate dynamism and to recognize the limits of the quantities to be produced or ordered that generate optimal costs and profits.

The costs in inventory management can be reduced by developing alliances between the buyer and the supplier, in addition to reducing inventory costs, it is necessary to measure the profitability of these, through an indicator that allows knowing the return on investment in inventories.

5 Methodology

The following describes the methodology for performing a sensitivity analysis of the response of inventory models within defined limits determined by the system input variables and the GMROI calculation. The methodology can be applied to traditional and collaborative inventory models:

- Identify the mathematical model of the inventory.
- Calculate the optimal quantity to order or produce (Q*).
- Obtain the total cost of inventory K(Q*).
- Set up an interval of integer values for the quantity Q.
- A constant β is proposed that allows measuring the change between the optimal quantity to order Q* a quantity Q. The values of β are calculated with the following expression $\beta = \frac{Q}{Q^*}$
- Performs the calculation of $f(\beta) = \frac{K(Q)}{k(Q^*)}$ this function indicates the change in inventory cost related to the change in the quantity Q contained in the range of values to analyze.

- Prepare a table to present the necessary calculations for the sensitivity analysis; in the first column list the values of Q contained in the interval to be analyzed, in the second column place the calculation of K(Q) for each value of Q, in the third column calculate the value of β for each Q and in the fourth column place the calculation of $f(\beta)$.
- Make the graph that indicates the behavior of the sensitivity analysis.
- Perform the calculation of the gross margin of the return on investment of the inventory.

Following the proposed methodology, the sensitivity analysis was carried out for an inventory model for the buyer, supplier and a collaborative model which is presented in the following section.

5 Development of an example following the proposed methodology

Returning to the example proposed by Velásquez (2013) and taking the values proposed in his example, a sensitivity analysis is carried out for the inventory models of the buyer, supplier, and the collaborative model.

To show the applicability of Velásquez's collaborative model, it is necessary to add a dynamic dimension where the impact of modifying the economic quantity to order or produce is analyzed and the impact on the cost associated with the inventory is observed.

Sensitivity analysis is performed separately for the buyer's inventory model, the supplier's model, and the collaboration model. The data to develop the example are the following:

- Buyer: D = 2000 units/year, A_b = \$ 250.00 per order and h_b = \$ 4.00 per unit/year.

- Supplier: P = 10000 units/year, A_s= \$ 1000.00 per order and h_s = \$ 2.00 per unit/year.

The buyer and the supplier are in the same supply chain, so the demand from the buyer is the same as the quantity demanded from the supplier.

5.1.1 Sensitivity analysis for the buyer's model

Applying the EOQ model for the buyer, an optimal order quantity of Q^*_b= 500 with an associated cost K_b (Q) = \$ 2000.00.

To carry out the sensitivity analysis, the constant β is calculated, which allows measuring the change between the optimal quantity to be ordered $Q^*_b$and a theoretical quantity Q. For this analysis, all integer values in the range of 1 to 10 000 pieces were considered, with changes of one unit. Table 1 shows some values of β.

Table 1. Sensitivity analysis model of inventories for the buyer.

Q	Buyer Cost	$\beta = Q/Q^*_b$	$f(\beta) = K(Q)/K(Q^*_b)$	Supplier Cost	Join Cost
50	$ 10 100.00	0.098	5.151	$ 40 010.00	$ 50 110.00
110	$ 4 765.00	0.22	2.3825	$ 18 203.00	$ 22 969.00
500	$ 2 000.00	1	1	$ 4 100.00	$ 6 100.00
900	$ 2 355.00	1.8	1.1775	$ 2 402.00	$ 4 757.00
10000	$ 20 050.00	20	10.025	$ 2 200.00	$ 22 250.00

According to the values found, ordering an amount less than the optimum implies a higher cost than ordering larger amounts. Fig.1 shows the graph of the sensitivity analysis where it is observed that for values of β less than 1, the costs are very high while for values greater than 1 the cost K(Q) increases, but in a smaller proportion.

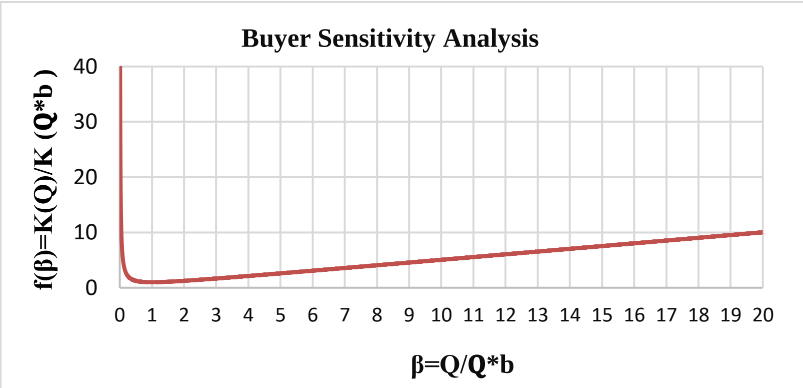


Fig. 1. Buyer inventory model sensitivity analysis plot.

Analyzing the costs, the buyer's model is the one that presents a greater increase in cost when β is greater than 1, which can be checked in the sensitivity analyzes shown in the following points.

5.1.2 Sensitivity analysis for the supplier model

Applying the inventory model for the supplier described by equations 7 and 8, an optimal quantity to produce of Q^*_s= 3162 is obtained, with an associated cost K_s(Q) = $ 1264.00, with these values, the sensitivity analysis described for the buyer's model is carried out. Table 2 shows a sample of some of the values obtained from the sensitivity analysis performed on the provider's model.

Table 2. Inventory model sensitivity analysis for the supplier.

Q	Supplier Cost	β=Q/Q$^*_s$	f(β)=K(Q)/K (Q$^*_s$)	Buyer Cost	Join Cost
50	$ 40 010.00	0.015812777	31.65348101	$ 10 100.00	$ 50 110.00
1500	$ 1 633.00	0.474383302	1.29193038	$ 3333.00	$ 4 966.00
3162	$ 1 264.00	1	1	$ 6482.00	$ 7 747.00
6500	$ 1 607.00	2.055660974	1.271360759	$ 13 076.00	$ 14 684.00
8000	$ 1 850.00	2.530044276	1.463607595	$ 16 062.00	$ 17 912.00

In Fig. 2, it can be seen that the supplier is less affected in its costs when it has to produce more than optimal, obtaining a more stable behavior, but if the quantities to be produced are less than optimal, costs rise exponentially.

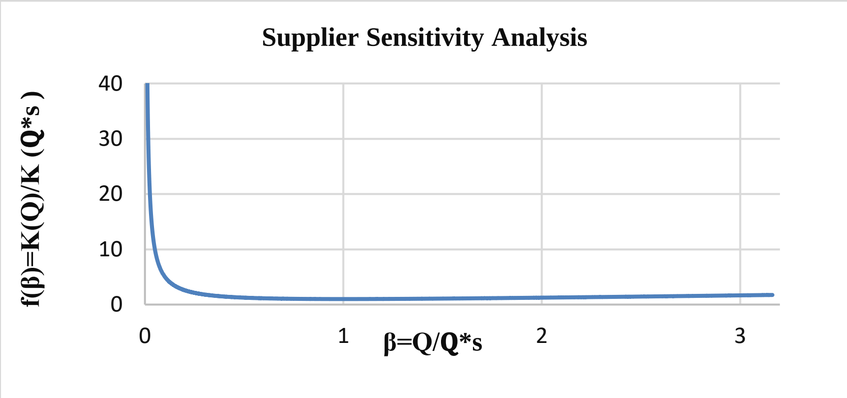


Fig. 2. Plot of supplier inventory model sensitivity analysis.

5.1.3 Sensitivity analysis for the supplier model

This model synchronizes the buyer and supplier so that they share an amount to order and to produce that allows to cover the interests of both and that reduces the costs of the supply chain. Table. 3 shows the optimal values Q^*_{bs}= 1066 and K^*_{bs} = $ 4690.00 calculated by the joint inventory model. The interval of Q was considered from 1 to 10000 pieces with the objective of contemplating any variation that could occur and through the sensitivity analysis, to contemplate any scenario and use it as a tool to make decisions to keep the supply chain efficient.

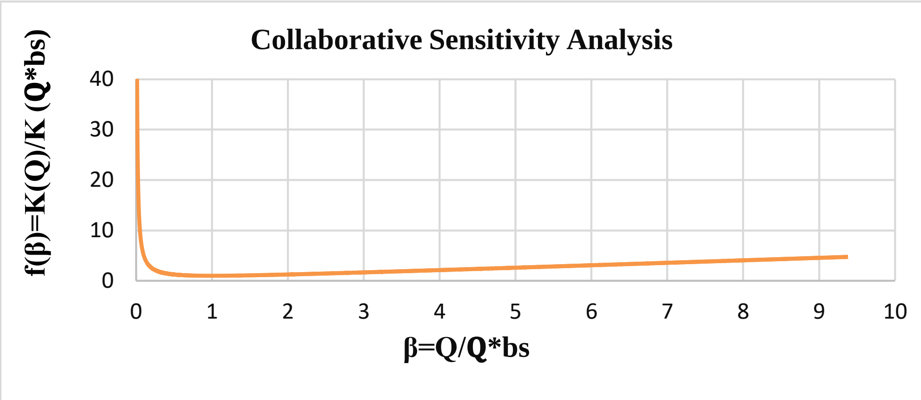
Table 3. Collaborative inventory model sensitivity analysis.

Q	Joint Cost	β=Q/Q$^*_{cp}$	f(β)=K(Q)/K (Q$^*_{cp}$)	Buyer Cost	Supplier Cost
250	$ 10 550.00	0.234521576	2.249466951	$ 2500.00	$ 8050.00
1000	$ 4 700.00	0.938086304	1.002132196	$ 2500.00	$ 2200.00
1066	$ 4 690.00	1	1	$ 2601.00	$ 2080.00

6000	$ 13 616.00	5.628517824	2.903198294	$ 12 083.00	$ 1533.00
10000	$ 22 250.00	9.380863039	4.744136461	$ 20 050.00	$ 2200.00

In Fig. 3, represents the sensitivity analysis graph of the collaborative model. This type of analysis is important for the buyer and supplier to be aware of so that they can make decisions together.

Fig. 3. Sensitivity graphical analysis of the collaborative inventory model.



As can be seen from the plots in Figures 1, 2 and 3 the buyer, supplier and joint model have similar geometry in the β domain from 0 to approximately 3.2.

The optimal quantity to order and produce that generates a lower cost in the supply chain is calculated by the collaborative inventory model, in Tables 1, 2, and 3 you can see the costs associated with the buyer and supplier when selecting the optimal quantities for each model.

5.2 Calculation of GMROI

If considering the annual sales for the buyer and the supplier of 2,000 pieces per year, the optimal quantity of order and produce of 1066 pieces is calculated by the collaborative model, then it is possible to calculate the gross margin and GMROI. These calculations are shown in Table 4.

Table 4. Calculation of GMROI collaborative model.

	Annual sales	Inventory	Gross margin	GMROI
Supplier	$ 780.00	1066	22 %	8.2
Buyer	$ 1000.00	1066	23 %	9.0

The gross margin indicates how much of the revenue remains as profit. Therefore, if the supplier's gross margin is 22%, as shown in Table 4, it means that he obtains 0.22 profit for each monetary unit of income, the same interpretation is to the gross margin calculated for the buyer. For the supplier, the gross margin also is used to measure the manufacturing costs, if the gross margin is low, it can decide to reduce the production costs.

The GMROI values shown in Table 4, express that for each monetary unit invested in the inventory, the return in a year is 8.2 monetary units for the supplier, and the for the buyer are 9 monetary units. Knowing the value of GMROI allows us to make decisions for inventory management and control as it is a measure of inventory productivity. When working with collaborative models, the GMROI calculation allows identifying the profit per monetary unit invested by the buyer and supplier, to ensure that both receive economic benefits by working together.

Analyzing the values obtained from gross margin and GMROI for the supplier and buyer, the optimal quantity to order and produce calculated by the collaborative model generates similar levels of profitability for both.

5 Conclusions

Sensitivity analysis is a tool that facilitates decision making, in the given example, it allows to identify the effects in the variation of the quantity to order or produce, drastic changes generate high costs that impact the profitability of the company. It can be concluded that from the sensitivity analysis carried out on the inventory models for the buyer, supplier, and group, the relationship of β less than 1 represents an exponentially higher cost, for β greater than 1 it also raises costs, but not as drastically as when it is less than 1. Therefore, in all three models, it is preferable to have a Q greater than the optimal value Q* instead of a Q less than the optimal.

When calculating the GMROI, the gross margin and the inventory turnover are combined, which allows analyzing the productivity of the inventory. For the developed case, the value of the GMROI is greater than one, which indicates that there is a profit for each monetary unit invested. According to the results presented, it can be concluded that the collaborative model reduces costs in the supply chain, because they approximate reality by relating the buyer and supplier. Collaborative mathematical models prove to reduce costs in the supply chain, but their implementation and success depends on the participation, communication, and organization of those involved.

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