Inventory Planning and Control with Optimization and Simulation Considerations: A Case Study

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Abstract

Objective: Inventory management is a process of vital importance in any company, currently in Cartagena - Colombia there is a great weakness in small and medium enterprises to plan and control their inventories. This project focuses on modeling for inventory management under an optimization and simulation approach. **Method:** The research is descriptive type based on ABC methodology, optimization and simulation techniques, which minimizes the gap between the theoretical basis and practice, facilitating a mechanism that leads to the reduction of complexity in the planning and control of inventories, in turn a contribution to decision making from a managerial sphere. **Findings:** The studied models allow to demonstrate that they are effective at the moment of having to decide on the quantities and the suitable moment for an inventory management, providing criteria of prioritization inside the warehouse, minimizing costs and establishing policies. **Improvements:** In the case study, the company will bet to the execution of own quantitative techniques of the industrial engineering for the planning and control of its inventories.

Keywords: Decision Making, Inventories, Optimization, Planning and Control, Simulation

1. Introduction

Manufacturing companies are characterized by the production of tangible goods, so generally, they have inventories, the proper administration or not of these can lead to success or failure¹. These inventories will be presented in the raw material inputs, during the process in the form of semi-finished products and in the outputs represented as finished products.

Planning and controlling inventories is one of the most complex contexts within supply chain management. The high investments that administrators, managers and those responsible for managing the chain must assume for a capital associated with raw materials, inventories in process and final products, constitute a potential to achieve improvements in the system². It is very common nowadays to find companies that although they carry out

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a planning and control of the inventories regularly fall in risk of excesses or shortages, due to unexpected changes in variables like the demand or times of delivery of products towards the client. Leading them to make decisions about the quantity of product to be ordered, the level of inventory to be maintained, and the required storage capacity, based on assumptions and past experience. The consequences are an effect on the company's level of service, working capital and available storage.

According to³, inventories also arise from the gap that exists between consumer demand and the production or supply of such products. However, these causes can be mitigated by the following strategies: (i) Obtaining accurate and real-time information on demand at the point of consumption. The more information available in a timely manner, the easier and more effective the planning will be. (ii) Consolidation of distribution centers and warehouses to increase demand volumes per facility, as higher demand volumes generally lead to lower levels of demand variability. (iii) The standardization of products to avoid the maintenance of inventories of a great diversity of items that only differ in minor aspects of form, color, condition, etc. The final product features can be implemented at the time of receiving orders from customers. (iv) Improving demand forecasting systems through widely recognized statistical techniques. (v) The improvement of alliances and communication systems with suppliers and customers to reduce delivery times, (vi) The issuance of joint orders for various groups of items in order to balance their inventory and the consolidation of shipments from or to localities, using facilities such as cross-docking and (vii) The reduction of delays throughout the supply chain, including transit times in transport systems.

In this case, and due to the fact that planning and inventory control have become transcendental activities that determine the success or failure of important objectives, the area of opportunity is generated, given that markets are increasingly demanding in relation to high quality processes and good service levels, requiring companies to face better quality standards, technologies and competitiveness. A contribution in this sense is provided by the existence of methods for the planning and control of stocks within the internal logistics of a company⁴. In line with this, inventory optimization and simulation has taken on great importance in recent years, given trends in market behavior, sales and competitiveness⁵.

An optimization model has three basic components: the decision variables to be determined, the objective to be optimized and the constraints to be met⁶. Also when doing a review of the thematic it was found that⁷ determined an algorithm to optimize production that served as a practical tool for the programming of orders. As a result,⁸ designed an optimal production plan in a bottling plant, seeking as an objective the optimal order quantities at a lower cost. At the same time,⁹ designed a mathematical model of optimization for the production mix in a footwear company, whose objective was to determine the optimal quantities and order of orders. More recently, design a model of optimization of entire mixed scheduling in multiple periods¹⁰, so that the costs of the logistics network can be minimized, considering missing inventories.

On the other hand, a simulation study makes it possible to lead to a better understanding of the system and therefore suggest strategies that improve operation and efficiency, in turn anticipating restrictions or bottlenecks or some other problem that may be limiting the process¹¹.¹² developed an inventory system based on the Montecarlo model that allows to control and manage in an optimal way the quantity of product and storage in the company, diminishing loss and improving response times. At the same time,¹³ designed a model to find the inventory policy with safety stock for a probabilistic model that maximizes the expected daily utility, considering that products are perishable and, therefore, can only be stored for a maximum number of days, and propose a methodology based on Monte Carlo Simulation. More recently,¹⁴ conducted a study of inventory management through simulation with system dynamics, where it is possible to know the behavior of variables according to the decisions made.

Currently in Colombia, when small and medium enterprises plan and control their inventories, they rarely contain techniques or tools that support this process and that in turn make it easier for the administrative decision making. According to studies on inventory management^{15,16} show that inventory costs in Colombian companies can represent about 20% of a company's sales.

These studies have also identified that about 65% of companies do not have support systems, tools or methodologies for decision-making in inventory management, mainly for three main reasons: (i) due to the high costs that this type of tools or techniques have, (ii) due to the lack of knowledge regarding the required input information, the variables involved in the process and the necessary elements for an adequate development and (iii) due to the lack of adequately trained personnel in inventory planning and control, since according to the studies carried out, this work is entrusted to low-ranking administrative personnel, with almost no training in this subject. Therefore, for the development of this research, enabling instances are provided to carry out as objective the design of a model for the planning and control of inventories with considerations of optimization and simulation, in a case study company of the metal-mechanic sector of the city of Cartagena -Colombia, which serve as support for decision making and benefit for the profitability of the company.

2. Materials and Methods

In order to identify policies and minimize inventory costs, the methodology presented in Figure 1 was used as a reference, which is based on the activities carried out by the companies, where complexity and volume of the entity's operations influence.



Figure 1. Proposal methodological.

This methodology is built from common techniques for the planning and control of inventories such as: (i) The ABC system, which is a means of classifying products, which are arranged in descending order of annual sales volume or use in monetary units. In inventory systems with several products not all have equal profitability. For this reason, it is important to differentiate between profitable and unprofitable items. The concepts of Pareto, who was an economist who studied the distribution of wealth in the nineteenth century and noticed that much of it belongs to a small segment of the population, are taken into account. This effect, called the "Pareto effect", also applies to inventory systems: a large part of the total monetary volume of sales is often due to a small number of items¹⁷. (ii) Optimization model, based on linear programming and economic order quantity, for this you need to determine the parameters, define the variables, build and solve the model. (iii) Simulation model, by means of the Monte Carlo method, based on data analysis, statistical parameterization of random variables, construction and solution of the model and finally scenario experimentation. The development of this methodology will allow to propose an improvement to the system, to support the decision making and to minimize the costs of inventories so that they obtain greater benefits for the company.

3. Results

This research begins with a study of the manufacturing sector in the city of Cartagena - Colombia. In this phase, a

general analysis is made of small and medium-sized enterprises in the manufacturing industry (Pymes), taking into account their classification according to the different economic activities, as well as the number of companies that make them up and their total assets. According to the Cartagena Chamber of Commerce, there are currently 32,535 companies distributed as follows: 29,576 (91%) microenterprises, 2,792 (8.6%) Pymes and large companies 167 (0.5%). Selecting the manufacturing industry, this is represented by a total of 3982 companies equivalent to 12%, until the end of 2017, the number of microenterprises were 3,669, Pymes of 278 divided into 224 as small and 54 medium and in the case of large companies a figure of 35. In terms of percentages 92% is equivalent to microenterprises, 7% to Pymes and 1% to large industries.

Taking into account the number of Pymes belonging to each subsector, it is evident that the most representative subsectors are those related to (i) Food processing with 38 companies. (ii) Manufacture of fabricated metal products, except machinery and equipment with 36 companies. (iii) Manufacture of chemicals and chemical products with 15 companies. (iv) Wood processing and manufacture of wood and cork products, except furniture with 14 companies. (v) Manufacture of rubber and plastic products with 13 companies and (vi) Printing and copying activities from original recordings with 12 companies.

Given the above, the sector chosen to carry out this research is metalworking, given the great importance for world economies, which includes all manufacturing companies engaged in the manufacture, repair, assembly and processing of metals, making significant contributions to the development of manufacturing industry globally, mainly in industrialized countries and is an indispensable engine of development for emerging countries¹⁸.

Initially, a diagnosis was developed based on a standard survey to identify the methodologies used to make decisions regarding inventory planning and control. This survey design included questions that investigated the generality of the company and the inventory system; the symptoms identified by the entrepreneurs in the management problem and the methodological aspects through which decisions are made were consulted. In total, 42% of the population of small and medium enterprises in the metalworking sector registered with the chambers of commerce of the city of Cartagena. When investigating the levels of inventory of raw materials, inputs and finished products, it could be seen that 92% of Pymes reported having problems with inventory levels either because of shortages or excess.

Then, for the application of the proposed methodology, a company from the metal-mechanic sector located in the city of Cartagena - Colombia was taken as a reference. Initially, field visits were carried out through direct observation and structured interviews with the leaders of the logistics management process. It was possible to establish that the logistics process, mainly the warehouse area, does not carry out a stock control of the inputs, apart from this, there is no inventory system that helps in the administration of these resources, in the control and monitoring of the stocks and daily needs of the process. Given the above, one of the main problems that the company must face on a daily basis is the existence of excess inventories. The company has on several occasions focused on having high levels of inventory, for lack of control of inputs, purchases are made without knowing the existence of the input. Which gives rise to an excess of these, this behavior within the company has led to increased costs, because there is no adequate technique to determine the behavior of demand, another point is that which focuses on the quality of inputs, as this is not stored in the proper way and the long time it takes the use of some inputs.

3.1 System ABC of Inventories

The ABC, Activity Based Costing, has been treated by different authors, such is the case of¹⁹ who pointed out that it consists of carrying out an analysis of the inventories establishing investment layers or categories in order to achieve greater control and attention on the inventories, which due to their number and amount deserve permanent vigilance and attention. In accordance with the conceptual foundations of the ABC method, a small number of products is responsible for a large volume of investment. The purpose of the classification is to establish a system of control by exception²⁰.

When applying the ABC methodology, the families of articles were listed, quantities and percentage of par-

ticipation or occupation in the warehouse area, then each one of the references of inputs associated with each family of articles was broken down, the monthly consumption of the articles was listed in terms of costs, then they were categorized or classified and finally an analysis was made of the results obtained. Table 1 below shows the classification of ABC inputs based on quarterly purchase orders generated in the 2016 and 2017 periods, which yielded the following quantities with their respective percentage of occupation in the warehouse.

Family of products	Quantity	Percentage of occupation
Chemical products Records Gases Accessories Solder Elements of endowment Electric Ferrous and no ferrous	44 41 65 153 25 13 74 89	9 % 8 % 13 % 30 % 5 % 3 % 15 % 18 %
Total	504	100 %

Table 1. Quantity and percentage of occupation at thestore of raw materials

Taking into account the years 2016 and 2017, the total consumption per accessory type input is the one that presents the highest percentage of occupation, therefore they are taken as a reference for classification (Table 2). Making an analysis of the results obtained in the ABC system of inventories, it is deduced that of the 100% of products housed in warehouse only 2% of the products of inventory that are equivalent to a quantity of 3 articles represent a quarterly cost of 46.500 USD and have a participation in the total consumption in 80% being located in the classification A. While the 28% equivalent to 43 of the articles represents a cost of 8,821 USD with a percentage of participation of 15% becoming the intermediate

Percentage	Items	Quantity	Participation	Costs	% Costos
0 % - 80 % 81 % - 95 % 96 % - 100 %	A B C	3 43 107	2 % 28 % 70 %	46.501 usd 8.821 usd 2970 usd	80 % 15 % 5 %
Total		153	100 %	58.292 usd	

Table 2. Classification of the raw materials

class articles and finally there are the articles of the classification of group C, with a participation of 70%, but that represent only 5% of the costs.

3.2 Optimization Model

To carry out the development of the linear programming model was used a computer with features of 10 GB of RAM and a 64-bit operating system with Windows 7. In order to determine the utilities and the optimum result of the variables, the GAMS (General Algebraic Modeling System) software was used, as its name indicates it is a modeling language, rather than a program to solve optimization problems. The mathematical construction of the model is described below, considering only the products classified as type A and belonging to the family of accessories. The case study process involves an "i" set made up of the families of products that may be incurred during a "t" time horizon. They propose as from this each one of the necessary sets for the construction of the model:

i	Families of classified products in A	(i:
1,2,3)			
t	Time's horizon		
(t: 1,2,.	3)		

The parameters of the proposed model are described, which are linked to demand, inventories, storage costs, supply costs, unit costs, lead time and budget.

Demand (di)	Sue average of products	
You sue projected (dp) Reques	t projected of products	
Lead Deceive (L)	Average time of provi-	
sioning		
Minimum inventory (Sm)	Minimum inventory	
permitted according to the data		
Maximum inventory (Smx)	Maximum inventory	
permitted according to the data		
Opening inventory (Si)	Opening inventory out	
of every product		
Buffer inventory (Ss)	Quantity of product	
foreseen for stock certainty		
Costs of supply (Ca)	Costs of replenishment	
for each product		
Maintenance cost (Cm)	Maintenance costs out	
of every product		
Costs of inventory (Cin)	Average cost of inven-	
tory		

Unit cost (Cu)	Unit cost	out
of every product		
Stipulated budget (Pe)	Budget	for
each family of product		

The variables of the proposed model are linked to the quantity of product of the family to be purchased during a period t and the quantity of product to be held in inventory in a period t. The variables of the proposed model are linked to the quantity of product of the family to be purchased during a period t and the quantity of product to be held in inventory in a period t. The model variables are then declared:

Q1 (i, t)	The family's quantity of product
i to buy at a period t	
Q2 (i, t)	Quantity of product to have in
the pipeline in a dete	rmined time.

The case study company's objective function is to minimize inventory costs. The equation [1], shows the mathematical formulation guarantees that the purchase process is carried out making the requirements with the adequate quantities and also, that the quantities of product in final inventory are reasonable according to the behavior of the consumption data thrown in monetary terms, in order to maintain the inventory in warehouse without surpluses, over-supplies or shortage.

$$Z_{\min} = \sum_{i=1}^{3} \sum_{t=1}^{3} Cu^* Q l + \sum_{i=1}^{3} \sum_{t=1}^{3} Cin^* Q 2$$
 (1)

Each of the model limitations is established, equations [2] to [3] represent the constraints associated with meeting demand, equation [4] is the constraint subject to the stipulated budget, equations [5] to [6] are minimum and maximum inventory level constraints and the [7] nonnegativity constraint.

$$S_{i} + \sum_{i}^{3} (Ql_{it} - Q2_{it}) = dp_{it}$$

$$Q2_{it-1} + Ql_{it} - Q2_{it} = d_{it}$$

$$\sum_{i}^{3} Ql_{it} * Cu_{i} \le Pe_{i}$$

Restriction of
fulfillment of the [3]
Restriction of
stipulated budget [4]

$\sum_{i}^{3} Q2_{ii} > Sm_i + Ss_i$	Restriction of minimal inventory	[5]
$\sum_{i}^{3} Q2_{ii} < Smx_i + Ss_i$	Restriction of maximum inventory	[6]
$Q1_{it}; Q2_{it} \ge 0$	Restriction of positiveness	[7]

 Table 3. Quantity of product i to request at the same time

Product	Period 1	Period 2	Period 3
Accessory 1	8	9	15
Accessory 2	10	2	8
Accessory 3	9	11	13

 Table 4. Quantity of product i to have t in the pipeline at the same time

Product	Period 1	Period 2	Period 3
Accessory 1	6	0	0
Accessory 2	7	0	0
Accessory 3	6	0	0

Tables 3 and 4 clearly show the results obtained in the optimization model, taking into account the optimum quantities that must be ordered and kept in inventory over a period of time. In a way that minimizes total inventory costs. This is equivalent to 478 USD taking into account only the sample of accessories as a product.

3.3 Model Simulation

The objective of the simulation is to be able to choose an adequate inventory policy that results in a good service to the clients and at a reasonable cost. The Monte Carlo technique is used to study the behavior of a system by generating random variables, pseudo-random numbers and probability distributions. The greater the number of iterations, the more stable the values obtained. It is, in general, a mathematical procedure that allows to simulate any physical system, of any type of branch of science that has laws that can be translated into a mathematical language. Taking into account the proposed methodology, to carry out the Monte Carlo simulation in this investigation, the historical data of the random variable demand for the three types of accessories categorized in level A were taken as reference. Subsequently, these data were statistically analyzed to determine the probability distribution that complies with the different tests and that most resembles this type of behavior. Table 5 shows the three types of accessories together with their probability distribution.

Table 5. Demand probability distributions of thevariable for each kind of product

Product	Probability distribution	
Accessory 1	Poisson (4,67)	
Accessory 2	Poisson (6,67)	
Accessory 3	Poisson (2,30)	

Table 6. Policies of inventory to play-act for type of product

Product	Policy of inventory				
	Present-day	Scene 1	Scene 2	Scene 3	
Accessory 1	Lot 23 Units, Tuesday and Thursday, without minimum stock	Lot 27 Units, Tuesday and Friday, minimum stock of 3 Units	Lot 30 Units, Wednesday, lower stock 20 Units	Lot 17 Units, Monday to Saturday, inferior stock 4 Units	
	436 usd	330 usd	380 usd	1092 usd	
Accessory 2	Lot 30 Units, Tuesday and Thursday, without minimum stock	Lot 25 Units, Tuesday and Thursday, minimum stock 10 Units	Lot 60 Unds, Thursday, lower stock 15 Units	Lot 18 Units, Monday to Saturday, Stock less than 10 Units	
	765 usd	1226 usd	641 usd	156 usd	
Accessory 3	Lot 8 Units, Tuesday and Thursday, without minimum stock	Lot 12 Units, Tuesday and Thursday, stock under 10 Units	Lot 16 Units, Wednesday, stock below 7 Units	Lot 11 Unit, Monday, Wednesday and Friday, shares less than 10 Units	
	273 usd	222 usd	245 usd	183 usd	

The following shows the construction of the event tables for each one of the types of products corresponding to the family of accessories, taking into account the random variable demand and the distributions of determined probabilities. These serve to be able to develop event by event the Monte Carlo simulation.

The simulation template was structured taking into account days, number of days, initial inventory, random numbers, value of demand, final inventory, missing inventory and quantities to be ordered. Table 6 shows the current policies for each of the products, along with the different inventory policies.

Analytically, the application of Monte Carlo simulation in this research allowed obtaining relevant results for decision making, in terms of establishing inventory policies for the different types of products. In the Table 6, it can be analyzed that for the company case study, for the accessory 1, the best alternative is the policy of scenario 1, given that the total costs of inventories decrease by 24.36%, for the accessory 2, the best alternative is the policy of scenario 3 where the costs decrease by 79.61% and in the same way for the accessory 3, where the best alternative is the policy of scenario 3 where the decrease represents 33.02%.

4. Conclusions

Today the business models of the modern world are in continuous development, entering new trends, new industrial areas and even new models in an increasingly dynamic and competitive environment. It is for this reason that in order to be aligned with the increasingly rapid growth of markets, organizations must manage and make decisions in the application of qualitative and quantitative administrative models developed for this purpose. Today, the management of inventory systems is one of the most complex functions in companies, so it involves keeping stocks to meet uncertain demands at specific periods of time. The manufacturing sector of small and medium enterprises is characterized by being dynamic, presenting high volumes of items or inputs and evidencing the absence of policies or systems that support an efficient management of inventories, bringing with it a high complexity when managing lines in the same way, mismatches in supply plans, low levels of customer service and increases in storage costs.

In this research it was found that inventory planning and control systems are not widely used in small and medium enterprises in the manufacturing sector and in turn the lack of an ideal method to manage inventories in companies. The application of the proposed methodology based on the application of techniques such as the ABC system of inventories, optimization model and simulation allowed demonstrating its effectiveness for management decision making in the selected case study company. Providing in turn criteria for prioritization within the warehouse, minimization of inventory costs and establishment of policies.

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