Variant of the EOQ Model for Electronic Products with Short Life Cycle

MSc. Andrés Velásquez Contreras
Profesor Universidad Autónoma de Colombia.
Doctorado en Logística y Dirección de la Cadena de Suministro
Universidad Popular Autónoma del Estado de Puebla.
21 Sur 1103, Puebla, Puebla 72410, México
Tel: (+52) 222 229 9400
andrestarcisio.velasquez@upaep.edu.mx

PhD Diana Sánchez-Partida
Profesora investigadora en el posgrado de Logística y Dirección de la Cadena de Suministro
Universidad Popular Autónoma del Estado de Puebla.
21 Sur 1103, Puebla, Puebla 72410, México
Tel: (+52) 222 229 9400
diana.sanchez@upaep.mx

PhD José Luis Martínez-Flores
En Ingeniería de sistemas. Consultor Master de Empresas.
Director del Posgrado en Logística y Dirección de la Cadena de Suministro.
Universidad Popular Autónoma del Estado de Puebla.
21 Sur 1103, Puebla, Puebla 72410, México
Tel: (+52) 222 229 9400
joseluis.martinez01@upaep.mx

Abstract
The life cycle of electronic products is becoming shorter. Calculate the optimum quantity to buy and hold in inventory is a big challenge, must be incorporated the temporary variable into the mathematical model that describes the death of the product and therefore calculate the required inventory. Economic Order Quantity (EOQ) was used in this case study in coordination with the logistic function, originally applied to population growth, this is a convenient function for estimating economic batch versus time analogy. Thus, a nonlinear regression was used to estimate the parameters of a hybrid model, EOQ-curve S. Once applied this model, the total costs of inventories were reduced by about 67%, demonstrating the effectiveness achieved.

Keywords
Economic Order Quantity - EOQ, Product Life cycle, S-shaped curves, Logistics function, Inventory levels.

1. Introduction
The design of inventory models tailored to each company is important as they solve unique problems with the possibility of generalization. For the present case, we worked in a commercialization company of varied electronic products, which are sold by Internet. The main objective is to solve the problem of over inventory, and therefore, high costs of inventory maintenance, especially obsolescence products. The demand for short-lived products is described as an S-curve, allowing an optimal Q to be established over time, which minimizes costs substantially as observed in the results (Spedding & Chan, 2000). We used concepts of inventories, optimization, statistics and costs, a combination
that together produced important results; Making the company more profitable. Then an empirical methodology was applied that allowed to formulate the model and to validate it by means of analysis of data, obtaining like result important theoretical savings.

The purpose of this article is to present an application of the Economic Order Quantity (EOQ) model considering the characteristics and variables of the product life cycle through the analysis of the S curves. One of the achievements was to design a dynamic model in the Time, sigmoid type adjusted to the life cycle of the product, which makes it closer to reality, unlike the original EOQ.

2. Literature review

Inventory management is a branch of operations management that arises from the need to optimize the economic resources allocated to the purchase or manufacture of products ensuring that these are available for sale when requested by the client. The questions that are answered with the methodologies of inventory analysis are related to the quantities to be ordered, the security inventory to be maintained, the quantity of orders to be made in the period, the frequency with which the orders are placed, and total logistic costs generated by each model, (Krajewski, Ritzman & Malhotra, 2010).

The first model of inventory management was designed in 1913 by Ford Whitman Harris, this model is known as Economic Order Quantity (EOQ), today has innumerable variants and applications, see in detail the literature review of (Bushuev et al., 2015). The EOQ basically illustrates the behavior of inventories and allows to balance the costs of ordering and holding inventories, (Heizer & Render, 2007). Figure 1 graphically depicts the EOQ considering the behavior of inventory maintenance costs (CM), costs of ordering (CO), and the sum of both costs or total costs of the model (CT); The point Q is the quantity to be ordered that minimizes total costs (TC), (Ballou, 2004). The EOQ formula is derived from the equalization of the functions of the cost of ordering and the cost of maintaining. The cost of maintaining is proportional to the ordered quantity, while the cost of ordering is inversely proportional to the ordered quantity.

Equation (1) expresses the equality:

\[ CM = CO \] (1)

When performing the substitution of values, the equality is expressed (2):

\[ \left( \frac{Q}{2} \right) h = \left( \frac{d}{Q} \right) k \] (2)

Finally, the formula (3) that determines the amount to be ordered considering both costs is:

\[ Q^* = \sqrt{\frac{2kd}{h}} \] (3)
The notation of the presented model is:

\[ k = \text{Cost of ordering ($ / order)} \]
\[ h = \text{Cost of maintenance (i * c)} \]
\[ c = \text{Unit cost ($ / unit)} \]
\[ i = \text{Inventory holding rate ($ / $ / time)} \]
\[ d = \text{Demand rate (units / time)} \]
\[ Q = \text{Economic order quantity (units)} \]

On the other hand, a classification is necessary to delimit the study area. The best known tool is the Pareto or ABC classification to the analysis performed on a family of data whose purpose is to group them according to the percentage they represent of the basic criterion to be measured. The classification methodology holds that the highest income in the economy tends to be distributed according to the 80/20 rule, according to which 20 percent of the population concentrates 80 percent of the wealth of a nation. Pareto's assertion is that in all countries, a small fraction of society controls a high share of wealth (Aljure et al., 2010).

The application of the Pareto model in the management of operations commonly takes as valuation criteria the value of sales, the profit margin, the value of the inventory, among other aspects (Bowenbox, 2007). The weights assigned to perform the classification in this work are listed below in Table 1.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Accumulated percent contribution range</th>
<th>Percentage of sample size</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0%- 79%</td>
<td>0%- 9%</td>
<td>Data that require a greater degree of control, since they present the highest value of contribution to the basic criterion of measurement.</td>
</tr>
<tr>
<td>B</td>
<td>80%- 94%</td>
<td>10%-29%</td>
<td>Data that require a medium degree of control, since they present moderate value of contribution to the basic criterion of measurement.</td>
</tr>
<tr>
<td>C</td>
<td>95%- 100%</td>
<td>30%- 100%</td>
<td>Data that require a low degree of control, since they present low value of contribution to the basic criterion of measurement.</td>
</tr>
</tbody>
</table>

On the other hand, analyzing the product life cycle is an analogy of life, originated by neo-Darwinian biology (born, grow, reproduce and die) applied to goods or service. The dynamics of the market evolves significantly, the consumerism, the perception of the client and the constant creation of innovations, causes that the life cycle of the product today is very short. For electronic and digital products like telephones, computers, televisions and printers, the life cycle is for months, Chung (2012).

<table>
<thead>
<tr>
<th>Aspects of Demand</th>
<th>Functional (Predictable Demand)</th>
<th>Innovative (Unpredictable Demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Life Cycle</td>
<td>More than 2 years</td>
<td>3 months to 1 year</td>
</tr>
<tr>
<td>Contribution Margin*</td>
<td>5% to 20%</td>
<td>20% to 60%</td>
</tr>
<tr>
<td>Product Variety</td>
<td>Low (10-20 variants per category)</td>
<td>High (often millions of variants per category)</td>
</tr>
<tr>
<td>Average margin of error in the forecast at the time production is committed</td>
<td>10%</td>
<td>40% to 100%</td>
</tr>
<tr>
<td>Average stockout rate</td>
<td>1% to 2%</td>
<td>10% to 40%</td>
</tr>
</tbody>
</table>
The product life cycle (CVP) is defined as the period of time elapsed since a product goes through the design, growth, maturity, decline to disposal phases (Krishnamoorthi, 2012).

The product lifecycle drastically influences the organization's strategy, the supply chain and especially in inventory management, Fisher (1992), in Table 1, defines the short life cycle between 3 months and One year, Table 2.

Figure 2 shows the product life cycle stages and the sales levels (Q) for each period (t). During the introduction phase the product is placed on the market and acceptance is low; In growth the product begins to have better sales due to the efforts put in during the launch; In maturity, sales grow continuously and consolidate reaching the highest point of the cycle; And during the decline and discard sales begin to decline quite as the product is replaced by new products.

The product life cycle can be represented by a S curve, provided that the performance function (sales or demand) is graphically accumulated historical data. Figure 3 presents the number of accumulated units that are placed on the market during the product life cycle (ΣQ (t), accumulated sales (Aguilar, Avalos, Giraldo, Quintero, Zartha & Cortes, 2012).

An S-shaped curve is usually adopted to define the product life cycle (ΣQ (t), accumulated sales), indicating the number of units that are placed on the market and therefore allows estimating the rate of return on the Based on the demand rate of a particular phase, as well as the calculation of the quantity to be kept in inventory (Buccini et al., 2011).
Logistic function as a model of population growth was first introduced by the Belgian mathematician Pierre-François Verhulst in 1838. The logistic equation was introduced to describe the self-limiting growth of a population. The equation is sometimes called the Verhulst-Pearl Equation. Today this model is often used to describe the dynamics of systems.

\[ N(t) = \frac{m}{1 + e^{-(ct+d)}} \]  

\( m \) = function asymptote  
\( c \) = Growth parameter  
\( d \) = Point of inflection

A product lifecycle can be divided into several stages characterized by revenue generated.

3. Description of the problem

This article aims to find a model for products with defined short life cycles between 12 and 52 weeks (Fisher, 1997), which minimizes the total inventory costs related to storage, ordering, missing and excess inventory.

The company is characterized by:

- Offer more than 250,000 products.  
- To be the largest investment in online marketing in Latin America.  
- Be addressed to all sectors and ages.  
- Have a team of more than 1000 people.

It is a growing company that seeks to strengthen its operation in a technical way, with concrete results. Inventory problems focus on excess inventory, technological obsolescence, and high maintenance costs, together with the inability to predict shortages and product deaths. The methodology that will be presented in the development of this article was applied to data provided by the commercial company in Colombia, this company has the need to improve the model of replenishment considering, therefore, to increase the level of customer service and reduce costs. The initial situation of the trading company is described below:

- The company did not have effective inventory policies, so it had excess inventory of low demand codes and missing high demand codes.  
- Control of inventories was done by means of a kardex systematized based on the Regional Repurchasing Model (own application). While the forecast of demand, quantities and frequency of purchase were calculated with a model based on the average weekly sales.  
- According to a survey conducted by the company, 17% of customers were completely dissatisfied with the service provided by the company. The findings of the study indicated that the root cause of dissatisfaction was related to shortcomings and deficiencies in the inventory.

Leftovers and missing are basically caused by the current EOQ calculation, which they perform in a traditional way. For example, for A1 the forecasted demand is 13,040 units, the company calculates it based on average sales up to the current period 250 units (22 weeks), average multiplied by 52 weeks (this forecast raises orders substantially and by both inventories), linearity is assumed for the projection. The costs of ordering and maintaining inventory are already calculated, for unit and per month, Table 3.

The stock or missing stock is calculated by subtracting the stock from stock. The estimated EOQ, for A1 is 53 units, the costs of ordering and storing are calculated, they add up to $ 4,194,447, finally the costs for missing or surplus are added, corresponding to 50% of unit costs for the number of Units, for A1, $ 26,561,503, for a total of $ 800,161,720, only for 10 items and for 22 weeks of operation. Total inventory costs correspond to the sum of the costs of ordering more storage costs and the costs of singers or over-stock.

All calculations are for week 23 and are projected through week 52.
4. Methodology

The EOQ assumes a constant demand and an improvement is to recognize that the demand varies with the time and in particular it diminishes, which as a direct consequence brings that the EOQ varied with the time. The 22-week sales database was taken for time series analysis; and for the life cycle time was defined as 52 weeks maximum. Finally, using a software, the parameters of the logistic function were optimized and by means of the minimization of the mean square error the adjustment curve was found. The product life cycle was divided into several stages characterized by revenue generated. The proposed model proposes to estimate the optimum production lot size (EOQ) and the total cost during the Product Life Cycle through the different phases.

For each $t$, a $Q^*$ is calculated, since the demand has a sigmoid behavior:

$$y_t = a + \frac{b}{1 + e^{-c(t-p)}}$$  \hspace{1cm} (5)

Notation:

- $y_t$ = Value of the function in period $t$
- $a + b$ = function asymptote
- $c$ = Growth parameter
- $p$ = Point of inflection

Where $y_t$ is the cumulative sales function, which describes the product life cycle.

![Figure 4. Example, Curve S, cumulative sales](image)

The $a$ and $b$ is the upper bound or maximum estimated sale, $c$ growth parameter, $t$ the time or analysis index and $p$ the point in time where sales start to decrease.
Therefore the demand $d_t$ is equal to, the expected maximum of sales and less accumulated sales until the projected period $t$:

$$d_t = y_m - y_t$$  \hspace{1cm} (6)

Where:

$$y_m = \frac{a}{r} + y_r$$  \hspace{1cm} (7)

The $y_r$ are actual cumulative sales in period, $r = 22$, and $t$ is the period with a planning horizon of 52 weeks.

$$d_t = y_m - \frac{b}{1 + e^{-c(t-p)}}$$  \hspace{1cm} (8)

Then the $Q^*$ is equal to:

$$Q_t^* = \sqrt{\frac{2k\left(y_m - \frac{b}{1 + e^{-c(t-p)}}\right)}{h}}$$  \hspace{1cm} (9)

So:

$$Q_t^* = \sqrt{\frac{2kd_t}{h}}$$  \hspace{1cm} (10)

5. Analysis of results

To estimate the parameters of the following logistic function:

$$y_t = \frac{b}{1 + e^{-c(t-p)}}$$  \hspace{1cm} (11)

The mean square error (MSE) was calculated, then by Excel solver, it is minimized by varying the parameters, until the optimum values are obtained.

$$Min \ MSE = \frac{1}{n} \sum_{i=1}^{n} (y_r - y_t)^2$$  \hspace{1cm} (12)
Table 4. Curve-s estimation

<table>
<thead>
<tr>
<th>Semanas</th>
<th>Yr</th>
<th>Yt</th>
<th>MSE</th>
<th>dt</th>
<th>Qt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1323</td>
<td>1539</td>
<td>46671</td>
<td>3732</td>
<td>617</td>
</tr>
<tr>
<td>2</td>
<td>2337</td>
<td>2404</td>
<td>4547</td>
<td>2866</td>
<td>536</td>
</tr>
<tr>
<td>3</td>
<td>3640</td>
<td>3323</td>
<td>100411</td>
<td>1948</td>
<td>437</td>
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<tr>
<td>4</td>
<td>4227</td>
<td>4092</td>
<td>18289</td>
<td>1179</td>
<td>337</td>
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<tr>
<td>5</td>
<td>4553</td>
<td>4617</td>
<td>4068</td>
<td>654</td>
<td>248</td>
</tr>
<tr>
<td>6</td>
<td>4716</td>
<td>4928</td>
<td>44789</td>
<td>343</td>
<td>178</td>
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<tr>
<td>7</td>
<td>4798</td>
<td>5096</td>
<td>89007</td>
<td>175</td>
<td>126</td>
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<tr>
<td>8</td>
<td>4948</td>
<td>5184</td>
<td>55504</td>
<td>87</td>
<td>88</td>
</tr>
<tr>
<td>9</td>
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<td>56928</td>
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<td>62</td>
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<tr>
<td>10</td>
<td>5030</td>
<td>5250</td>
<td>48182</td>
<td>21</td>
<td>43</td>
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<tr>
<td>11</td>
<td>5096</td>
<td>5260</td>
<td>27009</td>
<td>11</td>
<td>30</td>
</tr>
<tr>
<td>12</td>
<td>5129</td>
<td>5266</td>
<td>18684</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>13</td>
<td>5170</td>
<td>5268</td>
<td>9667</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>14</td>
<td>5183</td>
<td>5270</td>
<td>7502</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>5307</td>
<td>5270</td>
<td>1350</td>
<td>1</td>
<td>7</td>
</tr>
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<td>16</td>
<td>5407</td>
<td>5271</td>
<td>18614</td>
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<td>5438</td>
<td>5271</td>
<td>27983</td>
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<td>5483</td>
<td>5271</td>
<td>45031</td>
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<td>19</td>
<td>5504</td>
<td>5271</td>
<td>54367</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>5504</td>
<td>5271</td>
<td>54358</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>21</td>
<td>5505</td>
<td>5271</td>
<td>54821</td>
<td>0</td>
<td>1</td>
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<tr>
<td>22</td>
<td>5509</td>
<td>5271</td>
<td>56708</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Totales</td>
<td>5509</td>
<td>5271</td>
<td>38386</td>
<td>11070</td>
<td>2773</td>
</tr>
</tbody>
</table>

The values of the parameters obtained in the minimization were:

\[ b = 5270.86 \]
\[ c = 0.71 \]
\[ p = 2.25 \]

When replacing them, we have the curve \( y_t \), in addition, \( b \) is the upper or the maximum estimated sale, \( c \) growth parameter, \( t \) the time or analysis index and \( p \) the point in time where sales begin to decrease, inflection point, figure 6.

![Cumulative Sales Product A1, Nonlinear adjustment](image)

Figure 6. S curve, cumulative and adjusted sales.

In figure 7, it is evident that the \( Q_t \) decreases as the life cycle of the product A1 is exhausted.
Applying the dynamic EOQ model with short life cycle, sigmoid, logistic curve or S-curve, the order sizes decrease, that is, optimum Q as a function of time t, increasing the costs of ordering, but decreasing the costs of obsolescence of the inventory.

Table 5. Calculation of costs with the dynamic EOQ model. Cost situation for 10 items with the new model

<table>
<thead>
<tr>
<th>Name</th>
<th>SKU</th>
<th>Average sales</th>
<th>Maximum expected sales</th>
<th>Unit cost</th>
<th>Stock in Warehouse</th>
<th>Cost Order</th>
<th>Cost Storage</th>
<th>Q(t)</th>
<th>Over stock or missing</th>
<th>Costs Over stock and missing</th>
<th>Inventory costs</th>
<th>Total Costs of inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>250</td>
<td>5,530</td>
<td>1,002,321</td>
<td>154</td>
<td>16.207</td>
<td>41,627</td>
<td>4</td>
<td>150</td>
<td>75,174,064</td>
<td>22,487,930</td>
<td>97,661,994</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>165</td>
<td>3,639</td>
<td>161,705</td>
<td>639</td>
<td>4,625</td>
<td>3,119</td>
<td>7</td>
<td>632</td>
<td>51,098,723</td>
<td>2,415,354</td>
<td>53,514,077</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>151</td>
<td>3,337</td>
<td>706,987</td>
<td>0</td>
<td>28,617</td>
<td>11,226</td>
<td>10</td>
<td>10</td>
<td>3,534,936</td>
<td>9,606,659</td>
<td>13,141,595</td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>137</td>
<td>3,034</td>
<td>179,894</td>
<td>29</td>
<td>19,729</td>
<td>2,765</td>
<td>13</td>
<td>16</td>
<td>1,439,154</td>
<td>4,622,220</td>
<td>6,061,374</td>
<td></td>
</tr>
<tr>
<td>E1</td>
<td>116</td>
<td>2,551</td>
<td>24,226</td>
<td>3</td>
<td>119,395</td>
<td>2,669</td>
<td>28</td>
<td>25</td>
<td>302,827</td>
<td>10,916,117</td>
<td>11,218,944</td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>115</td>
<td>2,535</td>
<td>515,633</td>
<td>0</td>
<td>106,991</td>
<td>2,406</td>
<td>31</td>
<td>31</td>
<td>7,952,308</td>
<td>8,951,549</td>
<td>16,903,857</td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>112</td>
<td>2,481</td>
<td>22,267</td>
<td>24</td>
<td>126,255</td>
<td>2,110</td>
<td>29</td>
<td>29</td>
<td>167,001</td>
<td>8,073,560</td>
<td>8,240,561</td>
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</tr>
<tr>
<td>H1</td>
<td>109</td>
<td>2,414</td>
<td>1,142,484</td>
<td>2</td>
<td>66,404</td>
<td>5,136</td>
<td>16</td>
<td>14</td>
<td>7,977,389</td>
<td>10,061,624</td>
<td>18,039,013</td>
<td></td>
</tr>
<tr>
<td>I1</td>
<td>108</td>
<td>2,396</td>
<td>276,415</td>
<td>0</td>
<td>84,027</td>
<td>2,615</td>
<td>34</td>
<td>34</td>
<td>4,699,053</td>
<td>5,965,235</td>
<td>10,664,289</td>
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<td>2,340</td>
<td>736,148</td>
<td>52</td>
<td>67,345</td>
<td>6,130</td>
<td>14</td>
<td>14</td>
<td>13,986,806</td>
<td>11,297,911</td>
<td>25,284,717</td>
<td></td>
</tr>
</tbody>
</table>

| Totales | 166,392,262 | 94,398,160 | 260,790,422 |

The minimization was performed in the Solver optimizer to make the required nonlinear adjustment in the logistic function, finding the mean square error and estimating the optimal parameters. The results are very favorable for the proposed model, as shown in Table 5, for the first 10 products classified as A, in general achieves a cost reduction of 67.40%, in relation to the original model of the company.

Table 5. Summary of costs with the dynamic EOQ model

<table>
<thead>
<tr>
<th>Model</th>
<th>Cost of Over Stock and Missing</th>
<th>Costs of Inventory</th>
<th>Total Cost the inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOQ</td>
<td>781,166,732</td>
<td>18,994,988</td>
<td>800,161,720</td>
</tr>
<tr>
<td>Q(t)</td>
<td>166,392,262</td>
<td>94,398,160</td>
<td>260,790,422</td>
</tr>
<tr>
<td>Saving</td>
<td>614,774,470</td>
<td>(75,403,172)</td>
<td>539,371,299</td>
</tr>
</tbody>
</table>

The EOQ model is the one used by the company. Costs were calculated for the first 10 items (SKUs). When applying the dynamic model Q(t) based on the logistic function, the net saving is around $ 540 million. Tables 3 and 5.

In addition to the obvious achievements in cost reduction for inventory management, warehouse space was freed up and the efficiency of hand-to-hand operation over customer service increased.
Future research work should focus on a forecasting methodology and operations management for short-lived products.

CONCLUSIONS

It was possible to design a model for the control of inventories, for producer of short life cycle. This allowed us to reduce the costs of maintaining inventory and, in particular, to minimize obsolete inventories, also increasing turnover.

Today products have a very short lifecycle, which is not covered by most inventory models, but more and more often find sales structures based on innovation, reducing the life cycle of products and demanding a low level of inventory.

The techniques proposed here help to reduce inventory costs by approximately 67.40%, compared to the methodology used by the company to estimate the economic lot.

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References


Biography

**MSc. Andrés Tarcisio Velásquez Contreras.** Doctorate student of the Autonomous Popular University of the State of Puebla (UPAEP), in Logistics and Supply Chain Management. Magister in Industrial Engineering, Universidad de los Andes. Industrial Engineer, Universidad Distrital. Specialist in Logistics of Production and Distribution, Universidad of the area Andina. Research professor and consultant in organizational management, strategy, logistics and supply chain. E-mail: andres.velasquez@fuac.edu.co

**PhD Diana Sánchez-Partida.** She is a Professor and Researcher of the Postgraduate Degree in Logistics and Supply Chain Management at the Autonomous Popular University of the State of Puebla, her area of interest is in Logistics, Design and Optimization of Supply Chain and has participated in projects applied in the scheduling Schedules, levels and control of inventories and Planning and Control of Production. It can be contacted at UPAEP University, 17 Sur 901, Barrio de Santiago, Puebla, Puebla 72410, Mexico Tel: (+222) 222 229 9400 ext. 7783; E-mail: diana.sanchez@upaep.mx

**PhD José Luis Martinez Flores.** National Logistics Award 2013. SNI-CONACyT National Researcher. Consultant Master Business UPAEP. He is Researcher and Academic Director of the Postgraduate in Logistics and Supply Chain Management of the Autonomous Popular University of the State of Puebla. Its objective of research and consultancy is to design and implement models for the planning and optimization of problems in the field of logistics through the use of information technologies throughout the supply chain. It can be contacted at the Autonomous Popular University of the State of Puebla- UPAEP, 17 Sur 901, Barrio de Santiago, Puebla, Puebla 72410, Mexico Tel: (+52) 222 229 9400 ext. 7704; Email: joseluis.martinez01@upaep.mx

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