Multi-Echelon Inventory Management Policies: A Case Study for a Two-Echelon Supply Chain

Juan P. Escorcia-Caballero and René Amaya-Mier
Department of Entrepreneurship and Management and Industrial Engineering Department
Universidad del Norte, Barranquilla, Colombia
juane@uninorte.edu.co , ramaya@uninorte.edu.co

Milton Soto-Ferrari
Marketing and Operations Department
Indiana State University, Terre Haute IN 47807, USA
milton.soto-ferrari@indstate.edu

Odette Chams-Anturi
Department of Economic Science
Universidad de la Costa, Barranquilla, Colombia
ochams@cuc.edu.co

Abstract
Effective multi-echelon inventory management has been widely recognized for minimizing the average total inventory cost by promoting the coordination and cooperation among supply chain members. This paper presents a spreadsheet simulation of the inventory performance and associated costs obtained by developing a multi-echelon control policy in a real-world two-stage supply chain. Our simulation model is based on a supply chain network of a company located in Colombia and Panama. The results indicate an inventory cost reduction without negatively affecting customer service levels.

Keywords
Supply chain, Inventory policy, Echelon stock, Multi-echelon Inventory management.

1. Introduction

Supply chain members generally manage their inventories based on a decentralized policy, supporting their individual decisions on the inventory levels and performance objectives from a local point of view. Therefore, members usually ignore the implications of their decisions on their customers and suppliers (Escorcia-Caballero et al. 2019; Giannoccaro et al. 2003; Meindl and Chopra 2001). A decentralized inventory policy typically generates an excess of inventory without necessarily improving the customer service level (Gumus et al. 2010; Silver et al. 1998).

To address these issues, a strategy that allows for improved performance is a multi-echelon inventory policy, where inventory levels of each echelon in a supply chain are taken into account to enhanced inventory management coordination (Dai et al. 2017). Such a strategy is also known in the literature as a supply chain centralized policy, which concentrates on reducing inventories and associated costs without negatively affecting customer service levels of the echelons on a supply chain (Gümüs and Güneri 2007).

A significant number of authors had stressed the advantages of centralized management (Andersson and Marklund 2000; Axsäter 2000, 2001; Cachon and Fisher 2000; Dai et al. 2017; Forsberg 1997; Ganeshan 1999; Goh and Porteus 2016; Gumus et al. 2010; Guo and Li 2014; Korugan and Gupta 1998; Mitra 2009; Mitra and Chatterjee 2004; Mohebbi and Posner 1998), including benchmark reports that substantiate the interest of firms in implementing multi-echelon inventory models (Aberdeen group 2007; Eruguz et al. 2016). However, the literature review reveals a lack of real-world simulations and applications due to the computational complexity associated with the multi-echelon inventory policy implementation (Chu et al. 2015; You and Grossmann 2011; Yue and You 2013).Therefore, this research procures for the development of a simulation on an actual case study to evaluate the potential benefits in the implementation of a multi-echelon inventory system on a real-world supply chain.

Our case study relies on a supply chain network, which members are located in Colombia and Panama. The simulation focuses on a single product that flows throughout the network. Product selection relies on market relevance, and for the company, it is the highest demanded reference. The simulation's main objective is to replicate the effects and costs when a multi-echelon inventory management policy is applied within the context of a real-world supply chain. The proposed simulation is developed with the use of spreadsheets. This tool was selected based on the company's software preferences and the possible applicability of the policy on the supply chain.

This paper is structured as follows: we firstly review the literature related to multi-echelon inventory policies. Then, we describe the methodology of the research and the parameters for the proposed simulation model, followed by the study results. We finally discuss the results and provide case conclusions.

2. Literature Review

Inventory control policies for multi-echelon systems had been widely studied in the organizational literature (Mitra 2012). Clark and Scarf (1960) first introduced the multi-echelon inventory concept. A key aspect of their studies is the definition of the reorder point based on the echelon stock rather than in the installation stock, where the inventory position of each echelon is determined by the on-hand inventory, plus the addition of the in-transit inventory and the inventory position of the supply chain downstream echelons. Therefore, multi-echelon policy models take into account the effect that a given echelon's inventory decisions have on the other supply chain echelons (Eruguz et al., 2016).

From the concept of echelon stock, a significant number of authors have used different operating parameters and modeling assumptions to design and analyze inventory systems (Gümüs and Güneri 2007). A large number of mathematical models are found in the literature, such as those proposed by Andersson & Marklund (2000); Axsäter (2000); Dai et al. (2017); De Bodt and Graves (1985); Forsberg (1997); Ganeshan (1999); Gumus et al. (2010); Mitra and Chatterjee (2004). Most of these models assume stochastic or stationary external demand, and their objective is to establish an equation in terms of the total system costs, which determines the optimum lot size to be requested (Q) and the reorder point (R) in each supply chain echelon.

Specifically, De Bodt and Graves (1985) introduced a mathematical model of multi-echelon inventory management with fixed ordering cost and continuous review (R, Q) at all stages. Dai et al. (2017) suggested a multi-echelon inventory model considering partial backlogging with ramp, reverse-ramp, and trapezoidal demand types. Forsberg (1997) proposed a two-level inventory system (R, Q) with a central warehouse and N non-identical retailers that faced a Poisson demand distribution. Ganeshan (1999) proposed a near-optimal (R, Q) mathematical model for a network, with multiple suppliers replenishing a central warehouse. Axsäter (2000) developed a mathematical model for a two-level inventory system that integrated a central warehouse with N different retailers, where the external demand was generalized from a Poisson to a compound Poisson demand. Andersson and Marklund (2000) studied a two-level inventory system model with a central warehouse and N non-identical retailers, all using a continuous review policy (R,Q).

Mitra and Chatterjee (2004) introduced modifications on the Bodt and Graves model, leading to reducing the expected total cost of the system. Gumus et al. (2010) studied Mitra and Chatterjee proposed model and its generalization to N-echelons. In this context, approaches including (Chu et al. 2015; Güller et al. 2015) presented hybrid applications of simulation-based and agent-based optimization models. Subsequently, more recent developments proposed by Sakulsom and Tharmmaphornphilas (2019) introduced heuristics algorithms approaches for cost optimization when seasonal or cyclical demand is considered.

Most of the literature cases that report the implementation of multi-echelon inventory policies is based on examples of instances with generic demand simulated from several distributions. In our implementation, we focus the simulation on applying the policy in a real context with demand originated by the parameters of the market, including capacity constraints demarcated by the echelons on the supply chain. The entire simulation is developed using spreadsheets, as this is the software of preference for the companies. We applied a two-stage serial system in our multi-echelon inventory simulation since the particular context and requirements of the studied supply chain align with the model and provide the highest feasibility of adaptation within the actual network. A more detailed description of this model is presented in the following section.

2.1 Two-Stage Serial System

The two-stage serial system inventory model introduced by De Bodt and Graves (1985) is made up of a two-stage system: Stage 1 (retailer) supplies the external demand and Stage 2 (warehouse) deliveries product to the retailer. The model has been widely studied in the literature with modifications introduced to the formulations to take into account different types of distribution or patterns associated to the external demand (Andersson and Marklund, 2000; Axsäter, 2000; Forsberg, 1997; Ganeshan, 1999; Sakulsom and Tharmmaphornphilas, 2019). Most of the literature is related to the minimization of costs and the increase of the service level. A modification to the formulations presented by Mitra and Chatterjee (2004) proposed a reduction to the expected total cost of the two stage serial system. Specifically, when a system is under normally distributed end-item demand with deterministic lead time assumptions. This modification established the following notation for implementation:

D: expected demand per period
σ: standard deviation of demand per period
Q_i: order quantity at stage i
R_i: reorder point at stage i
A_i: fixed ordering cost at stage i
h_i: holding cost per unit per period at stage i
p: shortage (backorder) cost per unit at stage 1
L_i: lead time for replenishment at stage i

In this case, the retailer's inventory management (Stage 1) follows a continuous-review policy (R, Q). The policy evaluates the system's inventory position, and if the position is below the reorder point, the retailer will automatically place an order of size Q1 to the warehouse (Stage 2). This implication means that the operation of the retailer is the standard policy of independent inventories. Likewise, the warehouse follows a continuous review policy (R, Q), but the calculation of its inventory position is based on the echelon stock rather than the installation stock, thus centralizing the stock control for the entire supply chain, indicating that the warehouse uses a coordinated approach for its inventory control management. For the model, Table 1 presents the formulation for a continuous review (R, Q) multi-echelon inventory policy of a two-echelon supply chain.

Table 1. Parameters for a two-echelon inventory management policy for a two-stage system

Parameters	Equations
Order quantity at Stage 1 (Q_1)	$Q_1 = \sqrt{\frac{2\left[A_1 + \frac{A_2}{n}\right]\mathrm{D}}{h'_1 + nh'_2}}$ Where, $h'_1 = h_1 - h_2$ and $h'_2 = h_2$
Order quantity at Stage 2 (Q_2)	$Q_2 = \mathrm{n}Q_1$ Where, $n = max\left[\sqrt{\frac{A_2 h'_1}{A_1 h'_2}}, 1\right]$
Safety factor	$1 - \Phi(k) = \frac{Q_1(h_1)}{pD}$ Where, $\Phi(k)$ refers to the cumulative distribution function of a normal distribution

Reorder point at Stage 1	$R_1 = D_{l1} + k\sigma_{l1}$ Where, D_{l1} and σ_{l1} are the average demand and standard deviation of demand during l_1, respectively.
Reorder point at Stage 2	$R_2 = D_{l1+l2} + k\sigma_{l1+l2}$ Where, D_{l1+l2} and σ_{l1+l2} are the average demand and standard deviation of demand during $l_1 + l_2$, respectively.

3. Methodology

For this research, a two-stage serial system simulation is developed using the information from an actual supply chain consisting of a retailer and a manufacturer. The proposed simulation model considers two stages, Stage 1 is denoted as the retailer, and Stage 2 as the manufacturer. A single product is selected, given its large market share. This item or reference is a mass-consumption food industry product with an average life of 12 months that is sold to final consumers in individual PET bottles. Stage 2 (manufacturer) delivers the product packed in boxes, each containing an equal amount of PET bottles with the product. Boxes are dispatched at the request of Stage 1, who is responsible for the distribution to the final consumers. Figure 1 illustrates the actual supply system.

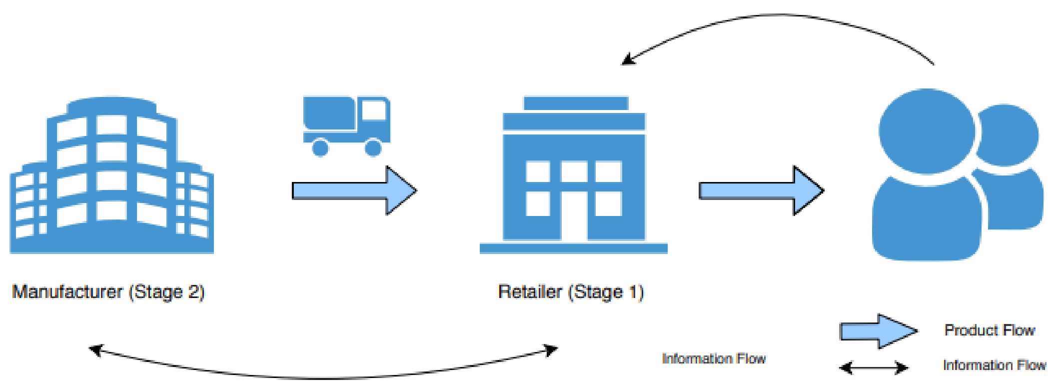

Figure 1. Studied supply chain

The simulation model monitors the end product inventories' performance for each of the stages or echelons considered on the supply chain. The simulation evaluates and calculates the impact in costs and inventories associated with implementing a multi-echelon inventory policy in the actual supply chain, and then we proceed to compare these results with the current single echelon inventory policies.

3.1 Simulation Parameters

Using companies historical data regarding to daily product demand, lead-time for replenishment, holding and fixed ordering cost, the parameters of the model were defined as follow:

D= 183.305/ year $\quad$ h_1= 0.29
σ = 70.91/day $\quad$ h_2 = 0.19
A_1= US 1303 $\quad$ L_1= 9 days
A_2 =US 1155 $\quad$ L_2= 2 days

Following the companies' requirements, the multi-echelon inventory management policy is performed with a safety-factor (k) equal to 3, simulating a customer service level close to 100%. According to the product's actual orders, the external demand follows a bell-shaped behavior closely. We use the parameters of the real data to create computergenerated demand values. The product's costs are equal to US15.30 per box and US14.78 per box, at the retailer and manufacturer echelons, respectively. Given these conditions and based on the equations presented in table 1, the calculated inventory parameters are:

$$Q_1 = 15517,\ n = 0.71,\ R_1 = 6050,\ \text{and}\ R_2 = 7952$$

The proposed simulation also considers constrains in regards of actual capacity of the supply chain. To clarify the implementation of the model and evaluation of the results, the specifications of the study are presented as scenarios. Table 2 details the schemes for each of the proposed scenarios.

Table 2. Scenarios Schemes

Scenario 1 (S1, without policy)	Illustrates the current real-system inventory performance of the supply chain under study. Inventory levels were established with the information provided by companies belonging to the studied supply chain.
Scenario 2 (S2, Optimal Multi-echelon inventory policy)	Illustrates the simulated inventory performance under a continuous review multi-echelon inventory policy according to the calculated parameters of order quantities and reorder points (Q1 = 15517, n = 1, R_1=6050, and R_2= 7952) .
Scenario 3 (S3, Agreement Multi-echelon policy)	Illustrates the simulated inventory performance under a continuous review multi-echelon inventory policy according to the parameters of reorder points. However, the order quantity at Stage 1 and Stage 2 are modified to 8000 units. This, to take into account the actual manufacturer production capacity and the limited purchasing power of the retailer Q1 = 8000, n = 1, R_1=6050, and R_2= 7952).

3.2 Simulation Development

We developed an algorithm arrangement to run the simulation synchronously for both Stage 1 and Stage 2 using Microsoft Excel® with Visual Basic for Applications (VBA). The performance of the multi-echelon inventory policy is analyzed using a single sheet, where it can be observed the demand flow, inventory on-hand, inventory position, inventory in-transit, missing units, and order quantities for the retailer (Stage 1) and manufacturer (Stage 2) period by period. The model computes the order quantity and reorder points for Stage 1 and Stage 2 using the equations presented in Table 1. To simulate the scenarios two and three, we incorporate the product demand per period at Stage 1 and the fixed ordering cost, and the holding cost per unit per period at Stage 1 and Stage 2 as described in Table 2.

The pseudocode for the multi-echelon algorithm arrangement is presented in this section. Where:

oh_r = Retailer inventory on hand; *d_r* = External demand; *lt_r* = Retailer lead time; *it_r* = Retailer inventory in-transit; *del_m* = delivered units from manufacturer to retailer; *ash_r* = Retailer cumulative shortages; *s_r* = Retailer shortages; *ip_r* = Retailer inventory position; *o_r* = Retailer order quantity; *lt_m* = Manufacturer lead time; *rop_r* = Retailer reorder point; *oh_m* = Manufacturer inventory on-hand; *it_m* = Manufacturer inventory in-transit; *lt_m* = Manufacturer lead time; *ps* = Manufacturer pending shipments to retailer; *oh_m* = Manufacturer inventory on hand; *d_m* = Retailer demand on manufacturer; *rop_m* = Manufacturer reorder point; *ash_m* = Manufacturer cumulative shortages; *s_m* = Manufacturer shortages; *ip_m* = Manufacturer inventory position; *o_m* = Manufacturer order quantity.

Retailer

```
ip_r = oh_r
For i = 1 To number_of_periods
  If i <= lt_r Then
     oh_r(i) = oh_r(i − 1) – d_r (i)
     ia_r = oh_r(i)
  End If
  If i > lt_r Then
     If oh_r(i) + it_r(i − lt_r) + del_m(i − lt_r)
                 ≥ as_r Then
          ia_r = oh_r(i) − as_r + it_r(i − lt_r)
                 + del_m (i − lt_r)
          as_r = 0
     Else
          as_r = as_r − it_r (i − lt_r) − oh_r(i)
                 − del_m (i − lt_r)
          a_r = 0
     End If
  End If
  If d_r(i) > a_r Then
     s_r(i) = d_r(i) − a_r
     a_r = 0
  Else
     s_r(i) = 0
     a_r = a_r − d_r(i)
  End If
  oh_r(i) = a_r
  as_r = as_r + s_r(i)
  ash_r (i) = as_r
  ip_r(i) = ip_r(i − 1) − d_r(i) + o_r(i)
  If i > lt_m Then
     If ip_r (i) <= rop_r and Q1 <
                 = oh_m(i) + it_m (i
                 − lt_m) and oh_m(i) + it_m (i − lt_m)
                 > ps Then
        intransit_r (i) = Q1
        order_r (i) = Q1
     Else
          If ip_r (i) <= rop_r and Q1
                 > oh_m(i) + it_m (i − lt_m) Then
             it_r (i) = oh_m(i) + + it_m (i − lt_m)
             o_r (i) = Q1
          Else
             it_r (i) = Q1
          End If
     End If
  End If
Next i
```

Manufacturer

```
ip_m = ip_r + o_m
For i = 1 To number_of_periods
  If i <= lt_m Then
     oh_m(i) = oh_m(i − 1) – d_m (i)
     a_m = oh_m(i)
  End If
  If i > lt_m Then
     If oh_m (i) + it_m (i − lt_m) >= ps Then
        a_m = oh_m(i) + it(i − lt_m) − ps
        s_m = ps
        del_m(i) = s_m
        ps = 0
     Else
        ps = ps − oh_m(i) + it_m(i − lt_m)
        s_m = oh_m(i) + it_m(i − lt_m)
        del_m(i) = s_m
        a_m = 0
     End If
  End If
  If o_r(i) > a_m Then
     s_m(i) = o_r(i) − a_m
     a_m = 0
  Else
     s_m(i) = 0
     a_m = a_m − o_r(i)
  End If
  oh_m(i) = a_m
  ps = ps + s_m(i)
  ash_m (i) = ps
  ip_m (i) = ip_m(i − 1) − d_r(i) + oh_m(i)
  If ip_m (i) <= rop_m Then
     it_r = Q2
  Else
     lt_r = 0
  End If
Next i
```

4. Results

This section presents the results obtained from the application. Figure 2 shows the performance of the inventory levels at Stage 1 (retailer) for all proposed scenarios.

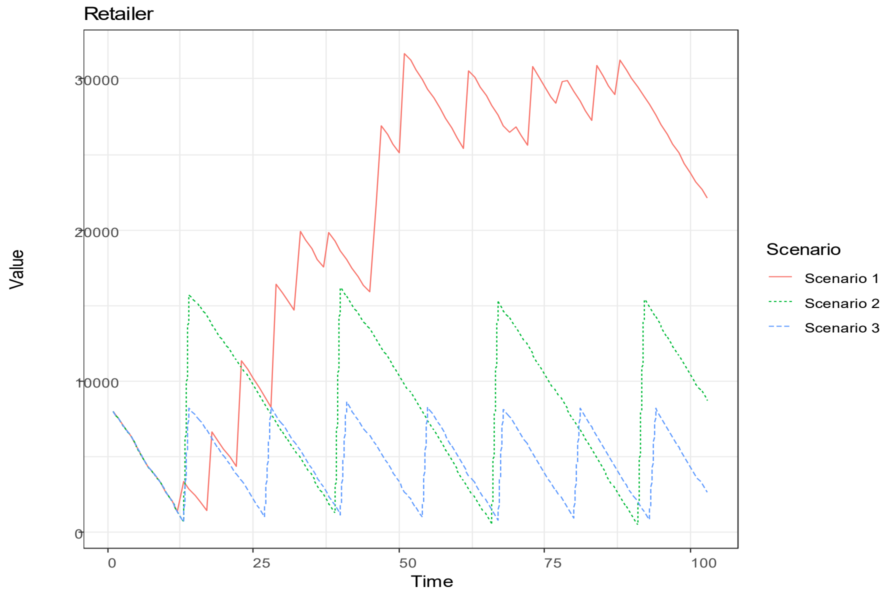

Figure 2. Stage 1 on-hand inventory level for each scenario

As observed in Figure 2, an overall inventory reduction is obtained for S2 and S3 at Stage 1. Figure 3 shows the behavior of the inventory levels at Stage 2 (manufacturer), for all proposed scenarios.

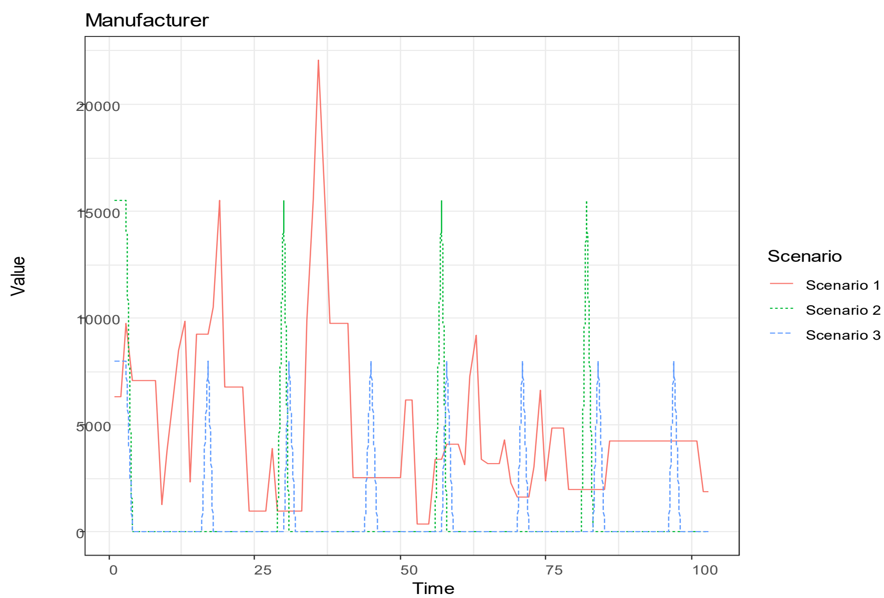

Figure 3. Stage 2 on-hand inventory level for each scenario

Similar to the findings in Stage 1, an overall reduction of the inventory levels can be noticed for S2 and S3 at Stage 2. The peaks values of inventory at S2 and S3, presented in Figure 3, represent fair product stock increases to support the requirements of Stage 1 at determined times. This inventory behavior avoids shortages or unnecessary product stocking. It is important to denote that given the constraints regarding capacity enforced in S3, both echelons showed a positive performance when real and actual limitations of the companies are considered. Finally, an analysis of the two-echelon aggregated stock strategy is introduced for each scenario and shown in Figure 4.

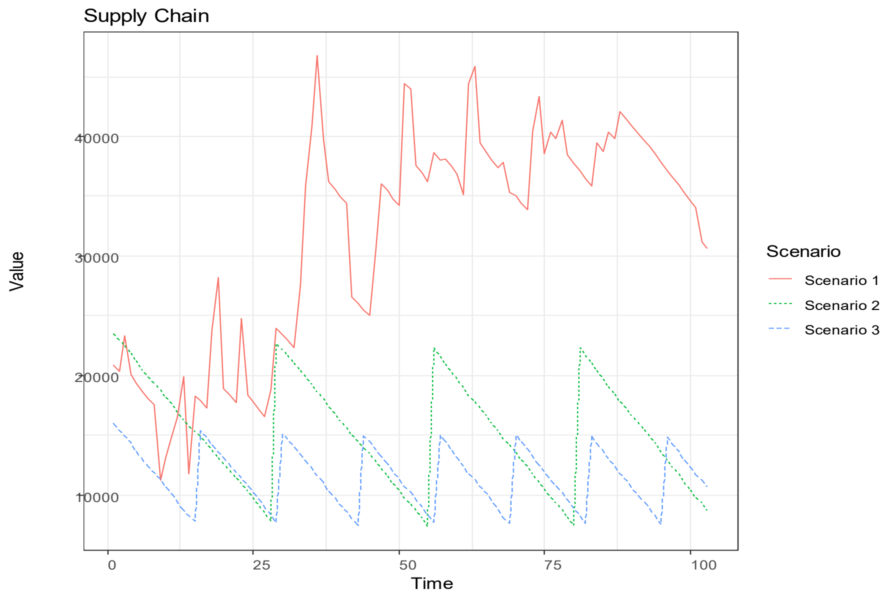

Figure 4. Supply chain inventory level for each scenario

Table 3 shows the calculations of the average inventory level, its percentage of reduction taking as reference S1, the number of replacement orders placed for Stage 1 (retailer), Stage 2 (manufacturer), and the global supply chain at each scenario.

Table 3. Global Supply Chain Inventory Evaluation

	Stage 1 (Retailer)			Stage 2 (Manufacturer)			Global supply chain		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Average inventory	25488,52	13812,69	10081,68	6286,8	1825,53	1840	31775,37	15638,22	11921,68
% of reduction	-	45,81	60,45	-	70,96	70,73	-	50,79	62,48
# of replacement orders	17	4	8	22	3	7	39	7	15
Backordered	0	0	0	0	0	0	0	0	0

The most significant % reduction of inventories in the two-echelon aggregated stock is at S3. This reduction is due to the lower order quantities used in this scenario compared to S2. However, replacement orders significantly increased in S3 due to the applied capacity constraints, increasing both order and total inventory costs at Stage 2. Table 4, taking as reference S1, summarizes the relative inventory cost reductions for each scenario. The inventory management global cost is calculated by adding the costs of holding stock and the cost of placing an order.

Table 4. Percentages of Global Cost reduction taking as reference S1

	Retailer	Manufacturer	Supply chain
Scenario 1 (S1)	-	-	-
Scenario 2 (S2)	66,1	85,7	73,2
Scenario 3 (S3)	66,6	72,4	67,9

The multi-echelon inventory management policy resulted in an overall reduction of the expected total cost for all the supply chain members. Compared to S1, the retailer obtained a reduction in the total cost of 66.1% and 66.6% for S2 and S3, respectively. Similarly, the manufacturer obtained a reduction in the total cost of 85.7% and 72.4% for S2 and S3, respectively. Finally, a general reduction of 73.2% and 67.9% for S2 and S3 is reached on the supply chain when a multi-echelon inventory management policy is implemented.

5. Discussion

The scenarios results showed higher performance in terms of costs when multi-echelon inventory policies are implemented. This better performance is an expected result since most of the available literature shows similar outcomes. However, the question remains, why not all supply chains apply a similar approach of multi-echelon inventory management policies if they are beneficial for its members to reduce overall costs? The reality is that in a practical context, most echelons or members of supply chains handle their inventory independently.

In a perfect world where unlimited inventory capacity or infinite restocking is available, the S2 scheme or scenario would be considered the optimal solution. However, in an actual application, such optimality is implausible because of the real-world constraints of mostly having to handle inventories on physical locations with restrictions associated with personal, software, time, and space. With the implementation of the S3 scheme, we intended to include in the model a segment of the complexity that companies have to encounter when applying these types of inventory policies. The real implementation would require the consideration of capacity and other limitations or restrictions associated with the specific supply chain.

In our proposed simulation, we incorporated into the model some of the difficulties in implementing the multi-echelon inventory policy. Probably, the most significant problem is the fact that members of a supply chain, when applying multi-echelons policies, are required to share information about demand and inventories. Consider that, in most cases, information is only available for local instances of a company, and it is not openly accessible for other echelons.

Our methodology's main idea is for the echelons to evaluate and understand the expected results of the application. We recommended to our studied supply chain members to consider the S3 scheme as the starting point for a real implementation. When a structured framework is established between the echelons, additional constrains can be aggregated into the simulation to create new scenarios in order to evaluate the operational feasibility of the updated schemes policies.

6. Conclusions

This study provides a clear understanding of the benefits of inventory levels, order and holding costs, and coordination levels among supply chain members that can be achieved through the implementation of multi-echelon inventory policies.. Our results support the conception that a centralized multi-echelon inventory policy has a better performance than a decentralized policy. We found important financial benefits to all analyzed supply chain members if they manage their inventory, applying a multi-echelon inventory policy. Therefore, it is suggested that the competitiveness of the supply chain could be increased with the policy's implementation, given the decrease in inventory levels, number of orders, and expected total costs.

Some degree of collaboration between members of the supply chain is required to apply a centralized multi-echelon inventory policy in a real context. After meeting with the staff members responsible for both companies' inventory management, there was consensus over the viability of shared inventory position data among the supply chain echelons. Therefore, the implementation of the proposed scenario is plausible without the generation of additional costs.

Future research might consider two or more products to evaluate their aggregated influence in multi-echelon policies for real-world systems, considering the impact of coordination problems, information flow delays, and untrusted behavior in the presence of multi-echelon inventory policies. Also, the evaluation of multi-echelon inventory policies on more complex supply systems could provide interesting stock performance insights.

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8. Biographies

Juan P. Escorcia Caballero is a professor of the Business School at the Entrepreneurship and Management Department, Universidad del Norte (Colombia). His research interests are Supply Chain Quality Management, Innovation, and Ambidexterity. He has published several journal and conference papers. He has participated in three research projects funded by the Administrative Department of Science, Technology, and Innovation of Colombia. Currently, he is part of a research project about Quality Management and Ambidexterity in the Organic Agro-Food Industry.

Milton Soto-Ferrari is an Assistant Professor of the Operations and Supply Chain Management program in The Scott College of Business at Indiana State University. He has published in recognized journal and research conference proceedings. His research interests include business and healthcare analytics, supply-chain management, logistics, and industry application of forecasting policies. Currently, he is the director of a research project related to the automation of advanced forecasting techniques in the industry.

René Amaya-Mier is full-time Professor in the Industrial Engineering Department at the Universidad del Norte, Barranquilla, Colombia. He earned B.Sc. in Industrial Engineering from Universidad del Norte, Colombia, Masters in Industrial Engineering from Universidad de Los Andes, Colombia and Ph.D. in Industrial Engineering from Florida International University, USA. He has published in recognized journals and research conference proceedings. His research interests include supply chain management, supply chain collaboration and gain-sharing, coordinated product and supply chain design, reverse logistics and system dynamics. He is member of IEOM, IIE, INFORMS, and the Center for Latin-American Logistics Innovation (CLI) as part of the MIT Global SCALE Network.

Odette Chams Anturi is a professor at the Science Economics Department, Universidad de la Costa (Colombia). Her research interests are Supply Chain Management, Organizational Learning, Innovation, and Ambidexterity. She has worked in public and private companies of mass consumption and healthcare entities. Currently, she is part of a research project about Quality Management and Ambidexterity in the Organic Agro-Food Industry.