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Research paper

Simulation of a stochastic multi-echelon distribution supply chain under a continuous inventory control policy

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Abstract

Multi Echelon Distribution System (MEDS) is a multifaceted system focusing on integration of all factors involved in the entire distribution process of finished goods to customers. This paper proposes a simulation framework at the operational level of MEDS. The proposed model includes three echelons, based on discrete-event simulation approach, where the performed operations within our system are depending on several key variables that often seem to have strong interrelationships. It is necessary to simulate such complicated system, in order to understand the whole mechanism, to analyze the interactions between various components and eventually to provide information without decomposing the system. The simulation framework is used to evaluate the performance of the considered system at initial conditions and to compare it with different scenarios generated by simulation running. The study concludes with an analysis of system performance and the finding results according to each scenario.

Keywords: *Multi-Echelon Distribution Supply Chain; Operational Level; Simulation Framework; Discrete-Event Simulation.*

1. Introduction

Multi-echelon inventory models are widely studied in the literature, there are different types of networks and inventory control methods investigated in this area. We talk about a multi-echelon inventory system, when a product passes through more than one node before reaching the end customer. In multi-echelon distribution system, several configurations are possible, from the simplest network where a single node provides the distribution of goods to the end customers (without including any intermediary); to the complicated network where products pass across multiple nodes and transportation ways, before reaching their final destination. The growing interest in multi-echelon distribution networks has in turn pointed out the importance of relying on efficient practices to manage his complexity and enormity.

In literature, researchers have studied a variety of problems in multi-echelon distribution systems. The current research is distinct from previous research because it combines all of the following features:

- An arborescent network in which each location has got a unique supplier.
- Demand occurs at the lowest echelon.
- Each node in the multi-echelon problem is subject to a stochastic capacity and demands.
- A stochastic lead time for supply exists between nodes.
- Excess demand is completely backordered.
- Holding, ordering and backorder costs are not necessarily identical across the retailers.

No existing research has considered all of these factors simultaneously, and provided a simulation solution to manage MEDS. Each of the points discussed above has been discussed separately in previous research, but no research has addressed all the issues. This makes the problems considered here closer to actual inventory and supply networks and allows us to provide a generic multi-echelon platform.

The objective of this work is to model and simulate a MEDS, which is assumed to have a moderate complexity of three echelons, to measure its performance under different scenarios and finally identify and understand its dynamic behavior. A discrete-event simulation approach is used to build the simulation model and measure the system's performance. The ability of understanding the whole system as well as analyzing the interactions between various components it's our goal for the simulation of multi-echelon networks. A flow models are provided to transform the system from a static representation to a simulation model. Further experimentation is then carried out on the model involving a number of designed scenarios. Conclusions are drawn on the behavior displayed.

The structure of this paper is organized as follows: the next section presents the characteristics of the multi-echelon system considered in this work. A brief literature devoted to simulation of multi-echelon distribution system is provided in section 3. Section 4 presents analysis of MEDS processes and describes step by step the designing and the implementation of the simulation model. The initial conditions and parameters of the developed simulation model are presented in section 5. The section 6 presents the results and discusses the major findings of the proposed eight experimentation scenarios. The paper concludes with the advantages of the developed simulation model.

2. Basic characteristics of MEDS

In control of MEDS there are several elements that define, the characteristics of the problem: the network structure, inventory control policies, allocation stock policies, system control, service level, and demand, etc. The following figure 1 highlights those characteristics:

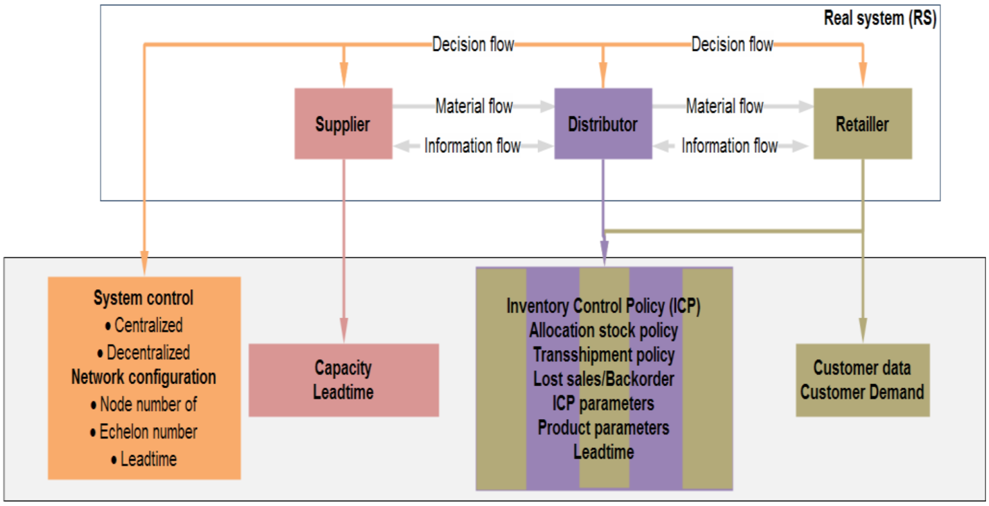

Fig. 1: Multi-Echelon Distribution System Characteristics.

2.1. Network structure

The characteristic of a MEDS is that the downstream stages are supplied by the upstream stages. However, in this context, there are several possible variation, and if transshipments between locations of the same level are allowed, the definition of a stage will not be clear. Four types of network structure are discussed in the literature:

- Serial system: this has a single location in each echelon.
- Diverged system: is a network in which every location is supplied by only one other location.
- Converged system: is characterized by the property that a node is supplied by more than one other stage, and supplies exactly one stage.
- General system: is a network that combines the diverged and the converged systems.

2.2. Inventory control policy

An inventory control policy can generally be divided into three distinct parts:

- Determining the order quantity;
- Determining the reorder point, or the inventory level at which a replenishment will be triggered;
- Determining the reorder interval.

Many standard policies are used to control inventory. These policies include continuous review policies and periodic review policies:

- Continuous review policies: EOQ, (S, S-1), (Q, r), order-up-to, and (S, s).

EOQ works in a deterministic framework. The (S, S-1) policy, the orders are placed every time a demand occurs, with a target of returning stock to the base-stock level. In this policy, inventory is replenished one unit at a time as demand occurs The (Q, r) policy, an order is passed when the stock falls to r, with an order amount of Q. The amount of order is defined as the quantity of inventory that will be produced or purchased when a replenishment order is placed, while the reorder point is defined as inventory position at which the replenishment process will be triggered. The (S, s) policy is similar to the continuous policy review (Q, r), except the quantity Q is not always constant, each time it changes to reach the S level.

- Periodic review policies:

In the case of periodic review policies (T, S, S-1), (T, Q, r), (T, S), and (T, S, s) which are similar to (S, S-1), (Q, r), order-up-to, and (S, s), remain to define the reorder interval is equal to the time between two successive orders and is also called the cycle length. In Periodic review system at every T units of time inventory position is checked.

2.3. Control system

The control system of MEDS is classified into two categories: centralized and decentralized. Multi-echelon systems are often decentralized in the sense that the management decisions are based solely on the installation. In the decentralized system each retailer directly and independently places orders to the outside supplier. An advantage of an installation stock policy is that it requires no inventory information at other nodes in the system due to the lack of information availability. In case of the centralized system, the replenishment and allocation functions are performed at the suppliers. One way to take control of the whole system is to use the echelon policy stock level. Since in the echelon stock policy the ordering decisions are made with complete knowledge of the downstream stages, it is essential that the information of other nodes is shared.

2.4. Multi-echelon dichotomies

A multi-echelon distribution supply chain is a complex and dynamic system. In an unstable environment, many uncertainties exist throughout the chain. Indeed, demand, lead time, distribution processes, complex interconnections between nodes and supply constraints represent the majority of the factors that change constantly and unpredictably and should be considered. It is important to note that these uncertainties are continuously evolving and their impacts are significant on the performance of the chain. The more important of these distinguishing complexities are expressed by the following dichotomies:

- Deterministic/Stochastic: In a deterministic model, demands or lead-time or capacity at each designated node are known in advance with certainty. For a stochastic model, the demands or lead-time or capacity are assumed known to within a given probability distribution.
- Single-Product/Multi-Product: A single-product model deals with only one product at a time, ignoring possible interactions with other products. A multi-product model considers a number of products simultaneously in terms of at least one interrelating factor such as a budget or storage constraint.
- Backlog/lost sales: A model assumes backlogging of demand if unsatisfied demands are retained and satisfied from later resupply. In the lost sales assumption, unsatisfied demands are not retained.

3. Related literature overview

Multi-echelon inventory models are widely studied in the literature; there are different types of networks and inventory control methods investigated in this area. Numerous models have been proposed to treat the multi-echelon distribution system. Some previous works, illustrate the diversity and the complexity of these categories of system.

Gurnani et al. considers an assembly problem where two critical components are required for the assembly into a final product, the demand for the final product is stochastic. The components that are procured from the suppliers are random due to the production yield losses [5]. Bollapragada et al. considers a two-echelon serial system with demand and supply uncertainty is considered. A non-zero lead time for component and end product assembly exists [2]. Shang and Song develop analytical guidelines for managing service constrained systems, with attention on the linkage between stages. A serial base-stock inventory model with Poisson demand and a fill rate constraint is considered [9]. Agus has studied a tow echelons with lateral transshipment between retailers. The authors considered the demand is Poisson distributed, and constant lead time between echelons [1]. Cong Guo and Xueping has investigated inventory control problems, in particular a network that consists of one warehouse and N identical retailers, which may have different ordering cost and lead time, and faces a stochastic demand. A continuous review system is considered in the proposed model. The objective was to determine the optimal inventory policy that coordinates stock levels between each echelon of the system [4].

The simulation approach is used by some authors when the analytical approach became too complicated to describe logistics systems. Brady studied a multi-echelon series network, considering the supply and the demand as stochastic, the simulation model was developed with Arena© and the aim was to assess the impact of the choice of flow management policy of each retailer's service [3]. Van Beek et al. simulated the dynamics of multi-echelon multi-product, using periodic review policy with predetermined lead times [11]. Ng et al. have simulated the running of supply chains composed of N echelons, with stochastic procurement lead times and they have compared the types of flow management policies [8]. Zare and al. have considered a two-echelon production-inventory system using the continuous review (r, Q) inventory policy where transportation times between the two echelons are generally distributed. They propose a heuristic to approximate the base-stock level in the warehouse as well as the batch order size at the DC [13]. Niranjan simulated a multi-echelon system by combining a convergent structure and series structure (three-, four-, five-and m-echelon), the model assumes that is stochastic, the procurement lead time between echelons is constant and the capacity is stochastic [7]. Wan and Zhao presented a simulation model for a multi-echelon made of five nodes (manufacturer, distribution center and three retailers), under the assumption that the demand and the procurement lead time are stochastic. The purpose of this model is to analyze the relationship between the fill rate and the average stock of the entire supply chain [12]. Considering the same structure of network adopted by Tsai and Liu, they presented a simulation-based decision support system for solving the multi-echelon constrained inventory problem. Their goal was to determine the optimal setting of stocking levels to minimize the total inventory investment costs while satisfying the expected response time targets for each field depot [10].

4. Multi-echelon system model development

4.1. Process analysis

This section aims to present the conceptual model; the conceptual model incorporates some concepts raised in the literature review. The model developed is still quite generic and allows the representation of several situations and aspects. This Model is presented as flow diagrams.

The figure 3 shows the lowest level of multi-echelon network (the set of n retailers involved). The retailer receives orders from customer. After each request, a test is performed to check the inventory level. In the case where the stock is insufficient, the order is canceled or satisfied in accordance with the allocation stock policy. But in emergency situations it is also possible to use lateral transshipments between adjacent retailers. These transshipments are faster but incur additional costs. Such lateral transshipments are common in practice. Models with lateral transshipments are usually more difficult to handle, and the available results are less general.

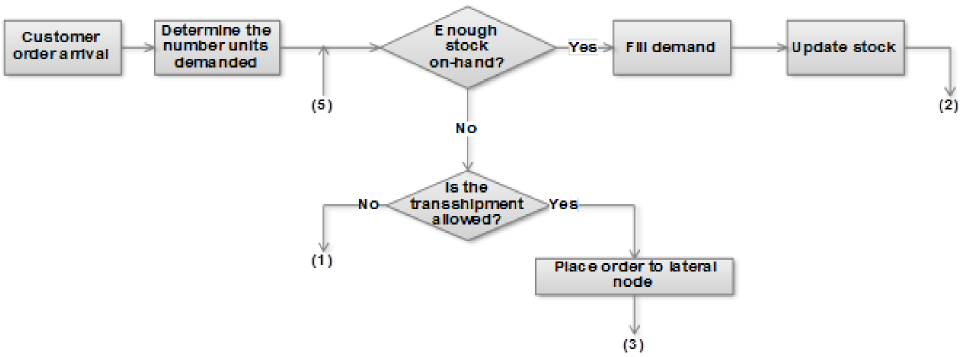

Fig. 2: Customer's Orders Management.

The flow management is to make all decisions for the short term, to coordinate all flows of the supply chain levels, in order to guarantee the service quality and minimizing costs. Choosing the right inventory control policy is crucial, because this choice will affect the entire distribution network.
The figure 4 shows the process of replenishment. The inventory inspection is triggered according to the inventory control policy, using a particular type of monitoring such as: "continuous" or "periodic". For each node, the inventory level is checked. If the inventory level is sufficient, no replenishment order is required for the node verified. Otherwise, if the stock level is insufficient, a replenishment order should be generated. The system uses installation stock policies, the replenishment policies based only on local information at the supplied installation. Such policies utilize only inventory position data (inventory on hand, outstanding orders, and backorders). In contrast, echelon stock policies require additional information in the form of inventory positions at the current installation, as well as at all downstream echelons.

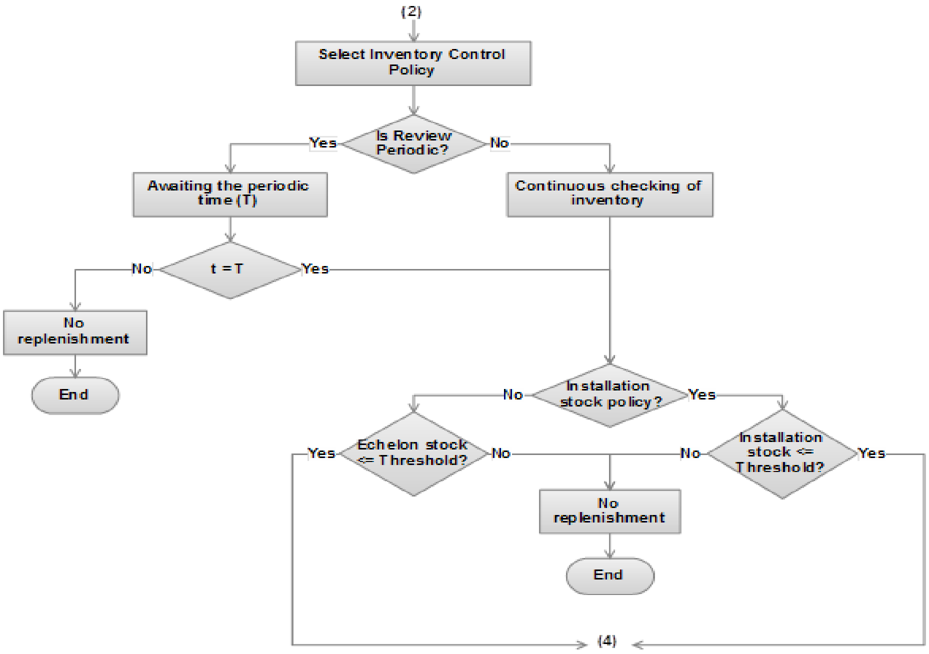

Fig. 3: Inventory Control Policy.

In general, when a stock out occurs two alternative policies can be considered: lost sale or backorder. The lost sale policy means that when there is an out of stock, the relative demand is lost, while the backorder policy means that when an out of stock occurs, the corresponding demand is backordered and filled as soon as an adequate sized replenishment arrives.
The allocation stock becomes important if a node receives a set of order more than the on hand inventory. In this situation, and as depicted in figure 5, the retailers or the distributors are forced to meet the excessive demand according to an allocation stock policy. There are several forms of allocation stock policy: Guaranteed allocation fraction, Maximum allocation, Fixed allocation, etc.

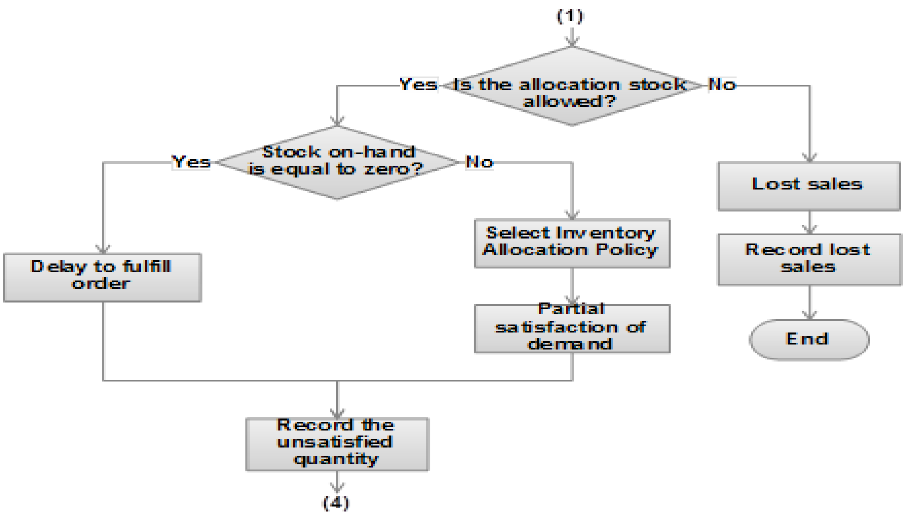

Fig. 4: Stock Allocation.

The figure 6 illustrates the upper echelons of multi-echelon network. Distributors, ensure the link between suppliers and retailers. We note that the running commands from the lower level to the upper level do not follow the same procedure as the management of customer's orders. Indeed, if the stock is insufficient, the command is never canceled, but it is treated depending on the allocation stock policy.

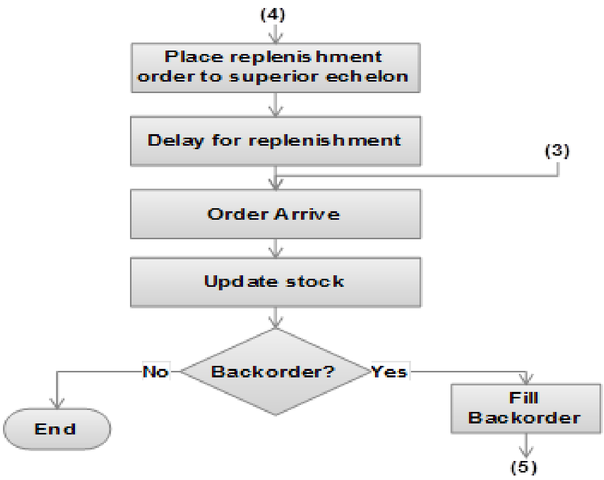

Fig. 5: Order Management.

4.2. Modules presentation

For simulating a multi-echelon distribution system, it is necessary to consider: material flow, information flow, and decision flow. It is also important to precisely model the interaction between the various participants (Figure 2). Each participant of the multi-echelon distribution system has his own set of activities. Despite differences between these activities, a number of processes are common to the participants of this system. These processes can be explained using a common set of terminology and enables the principle of reuse in bottom-up development of a model. To explore commonality between the participants, a set of modules can be built that can be put together to represent the various activities of the participants. Then these participants can be put together to obtain a model for the entire multi-echelon distribution system.

This fact is exploited to build standard modules that can be used for building multi-echelon system simulation models. Instead of building models from scratch, these standardized modules can be assembled to obtain the desired multi-echelon network. This can then be used to analyze different operational and strategic policies in the multi-echelon inventory.

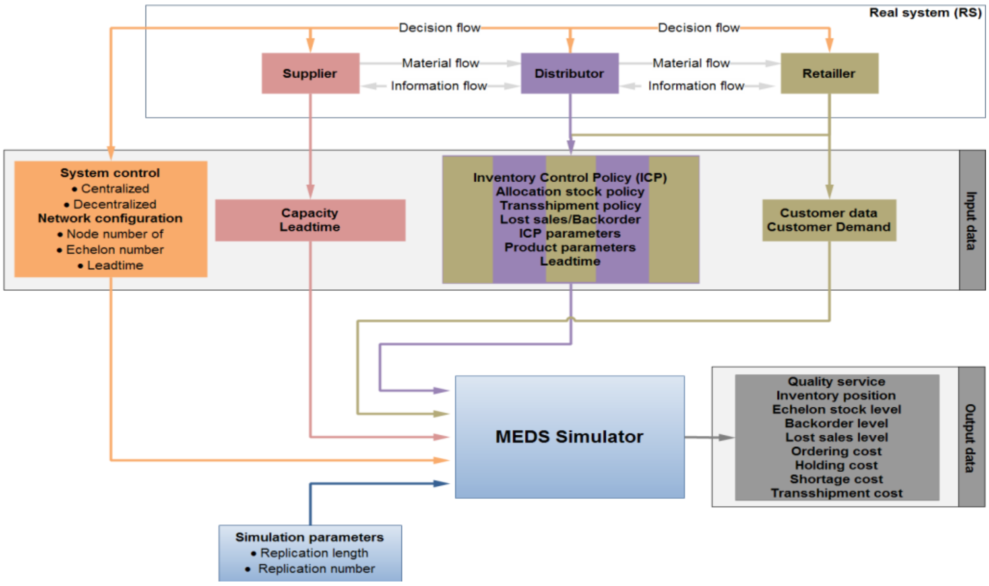

Fig. 6: Simulator Scheme.

For implementation of multi-echelon distribution system model, the costumers, retailers, distributors suppliers and inventory control modules are developed by Arena© software. The retailer module is designed to perform all the functions typical of a retailer. It is the only module that receives orders from outside customers. The simulation model modules (segments) are represented as follows:

- Retailers segment: the main processes concerning the retailers' module include order processing and inventory replenishment. More in detail, the retailer receives the customer orders and if its inventory is enough, it fills them otherwise they are backordered to await completion until the inventory becomes available. After the fulfillment, orders are delivered to the customers. The distribution process is triggered by a request of customer at the retailer level. Initially, the customer entity "Customer Arrives" allows the generation of demand throughout the simulation. Then, for each customer request, the quantity ordered is assigned in the "Customer Demand" block. When the demand for each product is defined, the retailer inventory inspection is done in "Is Retailer Stock Sufficient?" block. If the retailer has a sufficient stock, the customer demand is satisfied and its stock is reduced by the function "Retailer Stock - Sum of Demand" in the block "Decrease Retailer Stock", else the amount requested is put on hold by the function "Sum of demand – Retailer Stock" in block "Record Lost Sales" then a replenishment order is triggered in the block "Place Order To Distributor".
- Distributor segment: distributors module performs activities similar to the retailer one with the only exception that they refer to different suppliers and customers. At the distributor level, an entity is generated to launch the arrival of the retailer's orders in the

block "Retailer Order Arrives"; this entity can create orders for sourcing the requested products by retailers. Once the sourcing order is made, the inspection process (Variable Distributor Stock) of inventory turns. If the stock is sufficient, the retailer order is satisfied after a lead time ensured by the block "Distributor Lead Time" (follows a normal distribution), or else the not satisfied amount will be reserved to be fulfilled in the next replenishment (Record Retailer Backorder). The process keeps on running as long as the stock is sufficient by way of an update of the retailer inventory, and otherwise the order placed at the supplier level (Place Order To Supplier).

- Supplier segment: the supplier module is designed to accomplish the typical factory functions. As the focus of this study is on a production-distribution system, the module has been designed at a high level, which means that material procurement have not been considered here. So for the supplier module, whose main goal is to receive and fulfill orders coming from the distributor level, it has been designed with limited capacity. Finally, a customer module has been designed to accomplish the role of a customer that places an order directly to the retailer and does not have any connection to the other modules of the chain. In the supplier segment, the procurement process starts immediately after the arrival of the distributor orders, and if the supplier has no capacity restrictions, the order passes through the block "Supplier Lead time "representing the deadline of supplier. Thus, the inspection of distributor inventory is made to update its inventory.
- Inventory control segment: inventory control allows the encapsulation of rules to control the associated inventory. In inventory control module every node (retailers or distributors) is associated with inventory control policy; yet this policy does not have to be unique because inventory policy only provides information about the policy type, reorder point, and reorder quantity, etc. The way we designed the inventory control module can allow the stocks in a node to use the same policy for different products. On the other hand, inventory policy is a rule that governs the re-ordering behavior for inventory of a certain type at a particular node. The inventory policy determines when to order and how much to order. In addition, the “Allocation Stock Policy” block allows choosing the policy to satisfy partially an order, in case of exceed demand. In this model it has been chosen to adopt the backlog policy. In other words if the retailer, for instance, has sufficient products on stock, the customer receives the desired quantity. If not, the orders are accumulated in the backlog of the retailer, and the customer receives the desired products only after that they have been shipped from the distributor to the retailer.

5. Model background

5.1. Model indicators

For each inventory in the network, the following key performance indicators are maintained and can be displayed, Statistics are updated during the simulation:

- Customer service levels (e.g., the fraction of satisfied customer demands, known as fill rate).
- Total ordering cost, inventory holding cost and shortage cost.

5.2. Initial operating conditions

The system was first simulated under normal conditions, whereby the supplier capacity, distributors lead time and customer demand rate were assumed to follow a normal distribution with certain mean and variation figures. The results obtained by modeling the system in these initial conditions will be used as a reference to compare the system’s performance in a number of scenarios presented in section 7.
The system’s performance under initial conditions is shown in Figure 7. As the graph illustrates, quality service levels of the retailers remained above 95% all the period of simulation, and therefore there were no late deliveries during the entire modeling period also the total costs were normal.

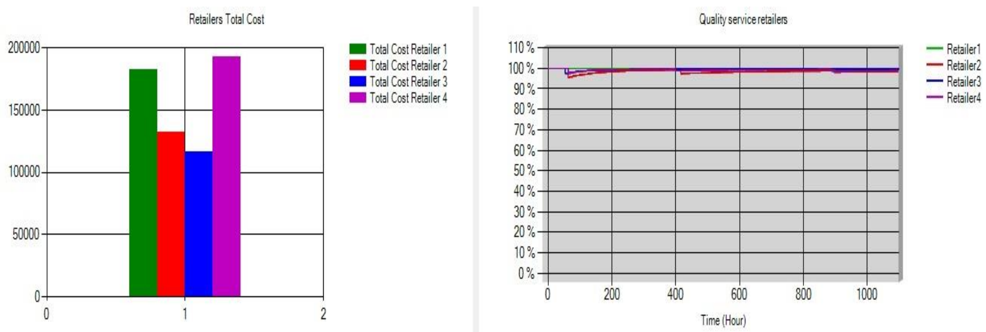

Fig. 7: Initial Conditions.

6. Results and discussion

6.1. Scenarios design

The authors propose as application example the investigation of 6 different scenarios. Each scenario has been run 16 hours per day and simulated for totally 2 months. Considering that demand is one of the most decisive factors affecting the network’s performance, four out of the overall six scenarios considered in this study concentrate on customer demand. The first four scenarios investigate on the effect that variability in demand frequency and demand intensity will have on the system’s performance. Demand for the four scenarios was manipulated by altering the mean of the normal distribution (as discussed in the initial conditions) while keeping the standard deviation constant. The fifth scenario involves changes in lead time, considering the case when lead time is lengthened on distributors’ level. Finally, the issue of working with reliable partners and more specifically supplier is considered in scenarios 6.

- Scenario 1 “high demand frequency”: the customer demand rate is very influential to the system; therefore, it is important to understand the effect that a sharp increase in the average demand rate will have on the system’s performance. The experimentations carried out as part of this scenario involved a step-by-step increase of the average demand rate up to 50% while the deviation remained the same as that described in the initial conditions.
- Scenario 2 “low demand frequency”: as demand can be highly unpredictable, scenario 2 explores the effect of the opposite case occurring, i.e. demand rate falls step-by-step down to 50%.
- Scenario 3 “high demand intensity”: in manufacturing environment demand is becoming increasingly more uncertain. Therefore, it is important to understand how a particular multi-echelon system responds to such changes. This scenario shows the effect of increased demand uncertainty on the performance of the multi-echelon network. The experimentations performed considered the case of 100% increase in demand variability.
- Scenario 4 “low demand intensity”: this scenario is the opposite of scenario 3 and is simulated to show the effect of fairly stable demand on the network’s performance. For this purpose, demand variability was assumed to be lower by 50%.
- Scenario 5 “increased lead time”: this scenario in fact considers the case whereby the retailers faces considerable lengthening of the distributors’ delivery lead time. In particular, a 100% increase in the lead time was considered. This means that there is a considerable lead time between the order being placed and the delivery of products. This scenario investigates on the effect of an increased distributors lead time on the customer service level and retailers costs.
- Scenario 6 “unreliable supplier”: variability in supplier capacity is a common problem in any supply chain. This scenario considers the case whereby the supplier capacity decrease and encounters some problem in filling distributors’ orders. It is a frequently experienced problem that suppliers may not have enough amounts of finished products to meet the requests of procuring.

6.2. Analysis of results

Scenario 1 “high demand frequency”:

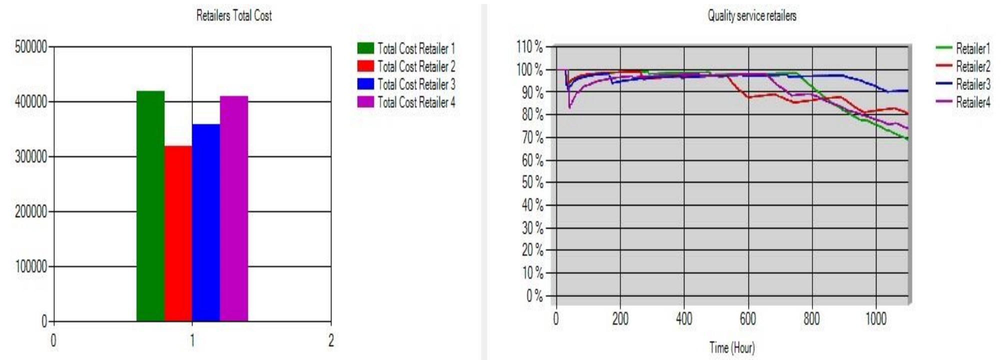

Fig. 8: High Demand Frequency.

Scenario 1 considers the impact that an increase in demand frequency has on the service levels and total costs. As Figure 8 shows on one hand, doubling the demand frequency generate a decreasing in customer service level and backorders becomes more frequent in the system. On other hand, there is a direct link between demand frequency and service level variability. In other words, as demand frequency increases there is a need to hold higher stock levels to keep 100% customer satisfaction.

Due to the inventory levels being particularly low as a result of the doubled demand, there is a shortage at the retailers’ echelon. To prevent this from occurring further in the modeling horizon, stock levels at the retailers’ echelon must be increased. However, the retailers will always need sufficient stocks to meet the demand frequency. If the reasons for the frequency are included then the variations in demand can be predicted and therefore stock held can be reduced.

Scenario 2 “low demand frequency”:

Scenario 2 simulates the system with a 50% reduction in demand frequency. The results showed that the customer quality service is become at 100% for all the retailers. Considering that scenario 2 is investigating the opposite case of that studied in scenario 1, the results obtained emphasized that the more the demand frequency is reduced the further stock levels can be reduced without any compromise on customer quality service. The total costs have dropped comparing to the normal conditions because of the decreasing of the orders number and thus decreasing of the ordering cost.

Scenario 3 “high demand intensity”:

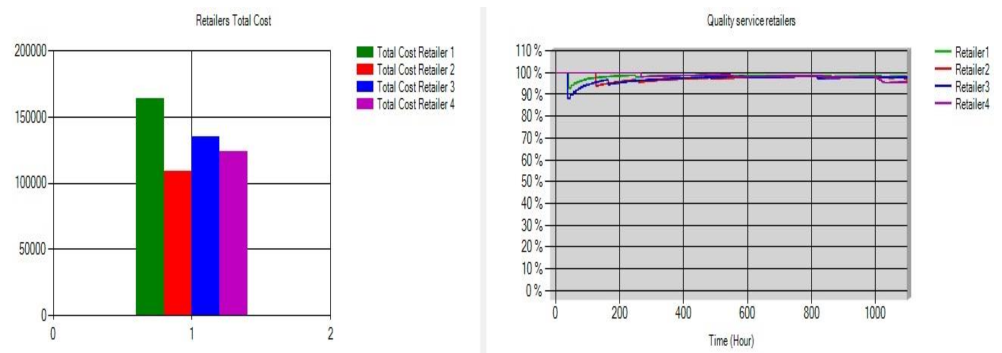

Fig. 9: High Demand Intensity.

The effect of a sharp increase in demand intensity by 50% on the inventory gaps for each echelon can be seen in Figure 9. As the figure illustrates, the stock level for the retailers are not highly adequate and customer satisfaction drops in first 200 hours and increase above 95% after. The results show a direct link between the demand intensity and the stock levels required to meet the demand.
In fact, the increased stock level caused by considering higher demand levels has additional improvement on customer satisfaction. However, the point in our cost analysis that further increases in inventory cause also the increase of the total costs.
Ideally, inventory levels are aimed to be as low as possible but increased inventory may be justified in order to meet the increased demand. The quantity of increased inventory would have to depend on the costs, profit margin and the consequences of having a shortage. Increasing the stock levels would, in that sense, be justifiable if the profit margin is high and the shortages can cause a loss of customers.
Scenario 4 "low demand intensity":
The third scenario simulates the system by considering a 50% decrease in demand intensity. The results are exactly the opposite of those obtained by experimenting with scenario 3. During the experimentations performed for scenario 4, it turned out that a 50% reduction in demand intensity, results in a decrease in total cost with the customer satisfaction in the maximum. Therefore, it is essential that the stock levels are set as low as possible so that maximum customer satisfaction is maintained.
Scenario 5 "increased lead time":

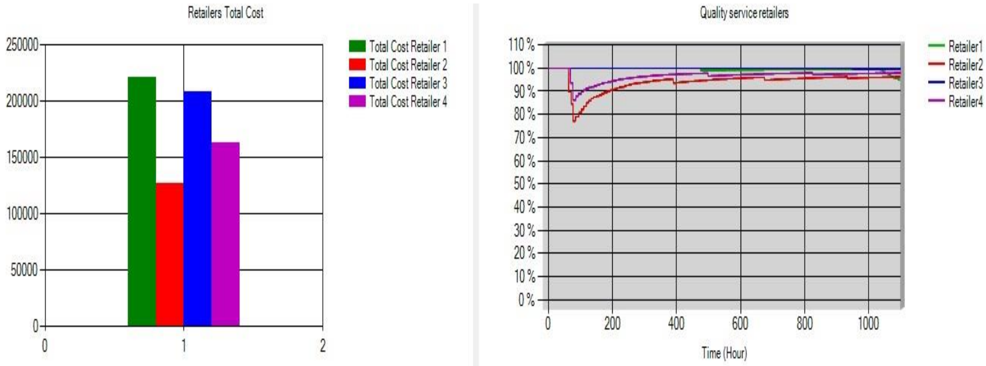

Fig. 10: Increased Lead Time.

Figure 10 shows the effect of increasing in distributors lead time on the quality service levels and costs. We should note the negative impact of the variability of the distributors' lead time on the retailers' quality service level. Considering the relationship between the distributors lead time and the retailers' quality service level, an increase in the first will inevitably result in a decrease in the second. Poor responsiveness from the distributor's side in turn, affects mainly the retailers' inventory levels as the retailers are more able to neutralize the effect of the late deliveries by using safety stocks. Therefore, all the retailers' orders are met and customers remain satisfied at the expense of higher retailer inventory. The increase in the lead time means it takes longer to deliver a product, this in turn means the costs become higher. When the distributors lead time increase the retailers' stocks level decrease to fulfill the customer demand, and then shortages become more frequent. The retailers suffer more as they have to hold high stock levels to maintain the same level of service. this shows that a benefit to keep high quality service can often cause an increasing in the total costs
Scenario 6 "unreliable supplier":

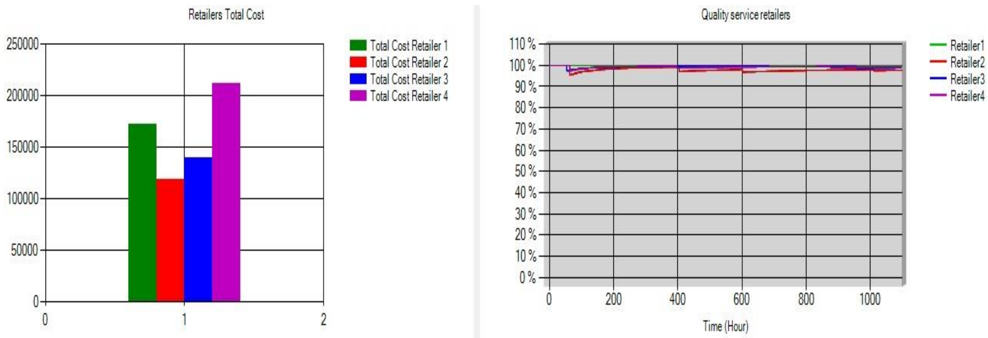

Fig. 11: Unreliable Supplier.

This scenario assumes that the supplier capacity decrease by 50 %. This causes retailer 2 to starve for products and experience some interruptions in customer demand satisfaction. Figure 11 shows that the safety stock held by the distributors and retailers are able to absorb some of the effect of the late deliveries from the supplier to the retailers.
The problem of supplier being unreliable is a commonly faced problem in multi-echelon networks. While a possible solution can be required by increasing the inventory levels, but the cost become higher as shown in figure 11. Supplier is the bottleneck in any supply chain, due to capacity constraints, when the flow of supplier is interrupted, lead time increases, the system becomes less responsive and the cost of shortage gets higher.

6.3. Discussion

In this section, the performance of the proposed simulation modeling system is evaluated by analyzing the 6 scenarios. All of these scenarios are dealing with the operational level of three-echelon distribution supply chain networks. From the above results, the following statements can be made:

- In case of high demand frequency, the stock levels would have to be increased by 40 % comparing to the initial condition in order to bring customer satisfaction level to 100% (figure 12). In fact, any further increasing in stock level caused by considering higher demand levels would have no additional improvement on customer satisfaction. The total cost increases at all retailers, due to the ordering cost and the holding cost increasing.

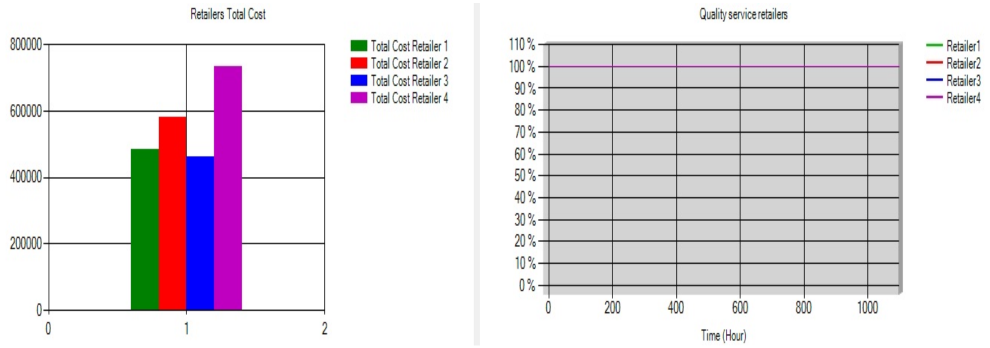

Fig. 12: Scenario 1- Adjusted Performance Graph.

- During the experimentations of scenario 2 (low demand frequency), it figured out that a 50% reduction in demand, results in 8% reduction in inventory while the customer satisfaction remaining at 100%. The effect of demand reduction on stock levels and overall costs might be clearly observed in the latest periods.
- In case of high demand intensity, in these scenarios the inventory must be increased by 28% to bring the quality service to 100% (figure 13). The total cost has increased comparing to scenario 3 due to increasing in holding cost.

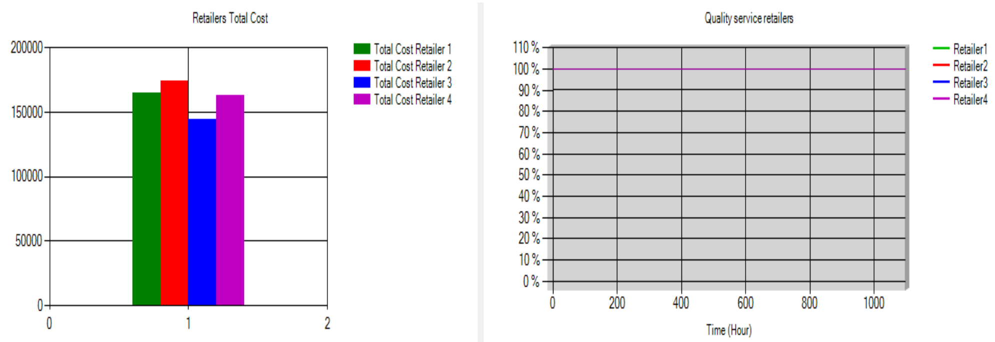

Fig. 13: Scenario 3- Adjusted Performance Graph.

- The analysis of low demand intensity has revealed that the safety stocks can be lowered by 8% with no impact on customer satisfaction. This shows the relationship between demand and inventory levels required to meet demand.
- In case of unreliable supplier, the inventory held by the distributors is able to compensate the effect of the late deliveries from the supplier to the retailers.

7. Conclusion

Several strategies of flow management and inventory management of multi-echelon distribution system have been proposed in the literature. Nevertheless, currently it is difficult to determine how each company must configure its own strategies, taking into account its own constraints and its special features. A simulation approach was proposed to evaluate these various options and their impacts on the multi-echelon system.

Complex and large multi-echelon distribution system processes can cause unexpected results, due to the dynamic interactions of different nodes involved in the network. One of the big tasks of multi-echelon inventory is to control these dynamic interactions which can have negative influences upon supply chains. In this study, a simulation model has been built for a multi-echelon inventory system including the retailing, and distributing, with the main goal of evaluating the effect of customer demand uncertainty, distributors lead time uncertainty and the variability of supplier capacity on this system. A different performance measures: quality service and total cost were used to study the performance of this system.

The results show that demand frequency and demand intensity have a significant effect on multi-echelon inventory performances. Therefore, increasing and decreasing demand frequency and demand intensity clearly emphasized that there is an inverse relationship between demand frequency/intensity and the stock hold at each echelon, and a direct relationship between demand frequency/intensity and total cost.

Furthermore, the distributors lead times and the supplier's reliability affect on the whole network performance in a similar manner. In case of disrupting the normal supplier flow and the delaying deliveries at the distributor's level, effect on the retailer's service level and total costs.

Future research can also look at the possibility of using echelon stock policy and benefits that can be achieved. Simulation model can also be modified to have more complexity by using centralized system control, other multi-echelon network and varying costs.

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