A generic conceptual and UML model for the multi-echelon distribution supply chain

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***Abstract*—The Multi-Echelon Distribution Supply Chain (MEDSC) is a multifaceted structure, focusing on the integration of all factors that involved in the overall distribution process of finished products to the customers. The growing interest in multi-echelon distribution systems has highlighted the need to adopt an appropriate approach to ensure the efficient management of their complexity. While there is a significant amount of analytical research modeling the MEDSC, few studies have used simulation models for this system. The objective of the paper is to model the operational level of the MEDSC network and to obtain a real reflection of its behavior. The permanent interaction among the various components of the MEDSC and the increasing complexity of such system requires a simulation model, which is able to integrate a set of dynamic characteristics and stochastic aspects. Furthermore, this model will be adapted to several configurations of the multi-echelon network. Thus, this research has twofold: first to recall the issues regarding the flow management and inventory control in the MEDSC, then using the object-oriented approach through the Unified Modeling Language (UML) to build a flexible supply chain model.**

Keywords : multi-echelon distribution supply chain; simulation model; unified modeling language; modeling.

I. INTRODUCTION

Multi-echelon systems have received considerable attention during the last decades, the growing interest in MEDSC networks has in turn pointed out the importance of relying on efficient management practices to manage the complexity, enormity and breadth of scope of this system structures. Most consumer and industrial finished goods are distributed through multi-echelon inventory systems of one sort or another. The term "MEDSC" conjures up images of products, or supplies, moving from manufacturers or suppliers to distributors to retailers to customers, along a chain, in order to fulfill a customer request. Fig.1 (1 to K: distributors, 1 to m_1: retailers related to the distributor 1) illustrates the basic structure of a multi-echelon inventory system.

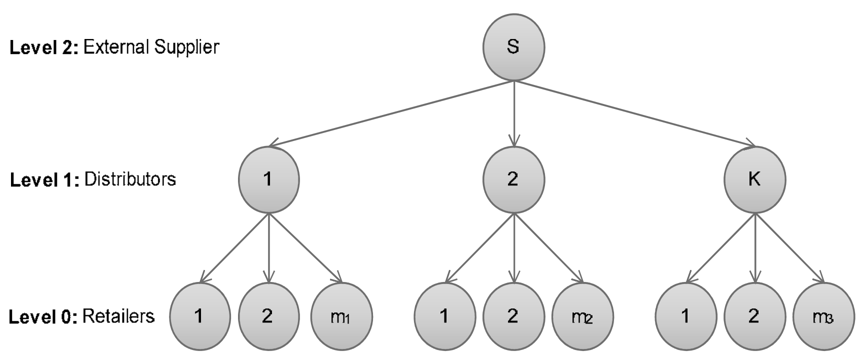

Figure 1. Simple multi-echelon inventory network

In MEDSC, several configurations are possible, from the most simple 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. Numerous concepts have revealed in the literature review that there are several features and configurations of multi-echelon distribution system, which complicate its management. Also, among the most important reasons for this complexity, we can mention [1]:

- The dynamic nature of interactions between all elements of the chain.
- The existence of a random nature of events in each network node.

- The size of system which is often large (dimension related to the structure).

Therefore, it is necessary to properly configure the multi-echelon system to get the maximum benefit in relation to the objectives set by the company. Thus the simulation modeling is proposed as a suitable tool for this task and to evaluate the impacts in a particular context.

In the literature review, several studies have focused on MEDSC modeling; most of them used analytical models rather than simulation models. Analytical solutions using mathematical tools such as probability theory and optimization can be used to obtain the approximate performance of multi-echelon inventory systems. Unfortunately, the analytical modeling of complex supply chains is limited to the underlying mathematical assumptions that make the mathematics tractable [2] [15]. For the performance modeling of complex supply chains, simulation turns out to be an excellent method for the evaluation of most of the systems where the relationships among the components are very complex.

This work has twofold aims, firstly, to analyze issues related to flow management and inventory management in MEDSC, and to recall the matters and challenges related to it. Secondly, then using an object-oriented approach to build a flexible supply chain model including Unified Modeling Language (UML) and provides some information to modeling this system. Indeed, UML is a modeling language using text and graphical notation for specifying, visualizing, constructing and documenting the analysis and the design phase of the system. Use case, Class, Sequential and State diagrams are the main tools of UML.

The major contribution of this research is to present a practical modeling system, which integrates different configurations of the upstream and downstream of the multi-echelon system. This model serves to build an important decision-making platform that managers can use for multi-echelon supply chain management.

The rest of the paper is organized as follows: Section 2 briefly defined the supply chain modeling techniques approach. Section 3 provides a brief literature devoted to MEDSC, and discusses our problem and the goals that motivated our research. Section 4 presents a conceptual model to describe MEDSC processes. Section 5 describes step by step the designing of the simulation model. Section 6 aims to discuss the ideas and actions conducted to develop this model. Finally, we will summarize our contribution and give outlooks of this study.

II. Supply chain modeling techniques and Concepts

Supply chain modeling approaches are dealing with complex systems, two modeling approaches have been most used, that are analytical modeling and simulation modeling [13] [4] [16]. The choice of one of these approaches is related to the studied system; Simulation model should be used when analytical approaches do not succeed in identifying proper solutions for analyzing complex systems (i.e. supply chains, industrial plants, etc.). The reason is that the analytical models are not able to describe the chain with all its complexity; as well the advantage of simulation in characterizing the stochastic behavior of logistics networks. These models can replicate the behavior of the supply chain in order to make forecasts and performance evaluation. They have the ability to capture the uncertainties and the dynamic behavior of complex systems. Indeed, the simulation modeling has been considered as one of the best methods to analyze supply chains and assess its performance.

In what follows, we focus on object-oriented development methods that are based on the UML, as they have demonstrated on many occasions their reliability and performance. Indeed, the UML (Unified Modeling Language) is a standard created by the merger of the three methods that have influenced object modeling in the mid 90: Booch, OMT and OOSE. Basically, UML has been used to model complex systems using the object oriented approach to bring them more formalism and methodology. However with the development of object concept, many studies use this standard to structure their reference models. The UML was designed to be a universal communication medium, to represent several complementary views of a system with several levels of abstraction. Also, it provides the needed standard patterns, it allows splitting the model into different diagrams, it keeps only relevant information, and it uses aggregation and generalization.

III. Literature revue and problem statement

A. Literature revue

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 MEDSC. Some previous works, illustrate the diversity and the complexity of these categories of system.

Cohen and Lee model a more general decentralized network in which the manufacturing site has multiple inputs, and its outputs feed a divergent distribution network. In this general decentralized network, the distribution model uses an (s, S) policy at each site [7]. Authors also assume end-product demands to follow a stationary Poisson process. Axsater provides algorithms for the analysis of continuous review policies in multi-echelon inventory networks. The model consists of two echelons. The lower one consists of n identical bases or stocking locations and the upper one consists of a single depot or warehouse that supplies the bases with repaired parts [3]. Lee and Billington develop an analytical model for a decentralized supply chain. Their model assumes each site operates under a periodic-review, base-stock inventory policy and the demands for end-products are normally distributed [14]. 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 [11]. 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 [5]. 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 [21]. Tlili et al. considered a three echelons system (supplier, warehouse and 2 retailers), with periodic review inventory control policy, where emergency transshipment is allowed to satisfy exceed demand [22]. 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].

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 [6]. Beek et al. simulated the dynamics of multi-echelon multi-product, using political control of periodic flows with predetermined lead times [23]. 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 [18]. Rossetti et al. have analyzed and simulated a system composed of N echelons and N products, and taking into account the fluctuation of demand. The model allows changing the management policy according to the forecasts of anterior demands [20]. 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 [17]. Wan and Zhao presented a simulation model for a multi-echelon made of five actors (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 [24]. Considering the same structure of network adopted by Wan and Zhao, Yu et al. developed a simulation model, with a continuous flow management policy (r, Q), to optimize costs of the inventory with taking into account the target service level [25]. Patil has adopted an integrated approach based on a simulation model, to reduce the cost and to improve sales of a network of two levels (distribution center, three retailers), with the introduction of emergency transshipment between retailers [19].

B. Problem statement and objective

In this paper, we have carried out a model of multi-echelon distribution system including the various features which are mentioned above, as it is summarized in fig. 2.

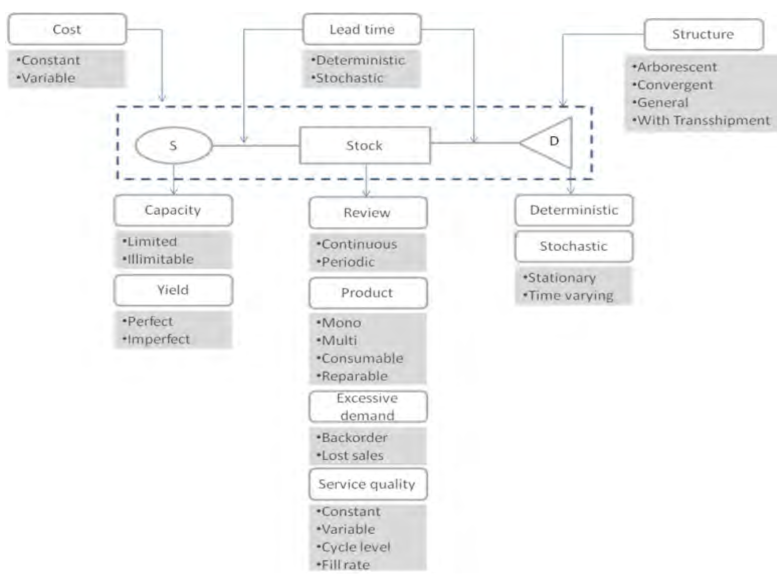

Figure 2. Characteristics of a multi-echelon supply chain [8]

Numerous authors have limited their studies to one or more sub-problems of distribution systems or they interested generally in the issue of multi-echelon distribution system of a particular company. However, this work aims to provide global solutions to problems related to the management of MEDSC.

Our contribution lies in the development of a simulation model that will bring solutions to a dynamic and stochastic behavior of MEDSC. Indeed, this model can be adapted to different configurations of a multi-echelon system and allows the evaluation of its performance in various contexts. Therefore, it will be easy to update this model of multi-echelon system in case of any change of its configuration.

IV. CONCEPTUAL MODEL

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 Fig. 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.

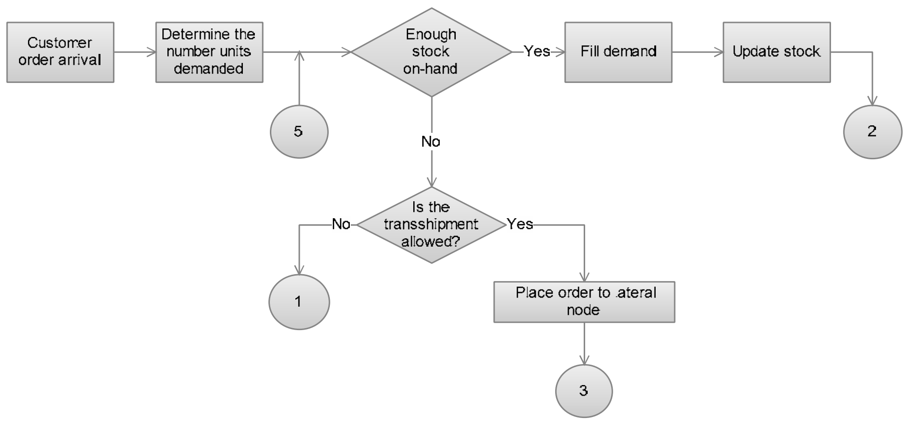

Figure 3. Customer's orders management

The Fig. 4 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.

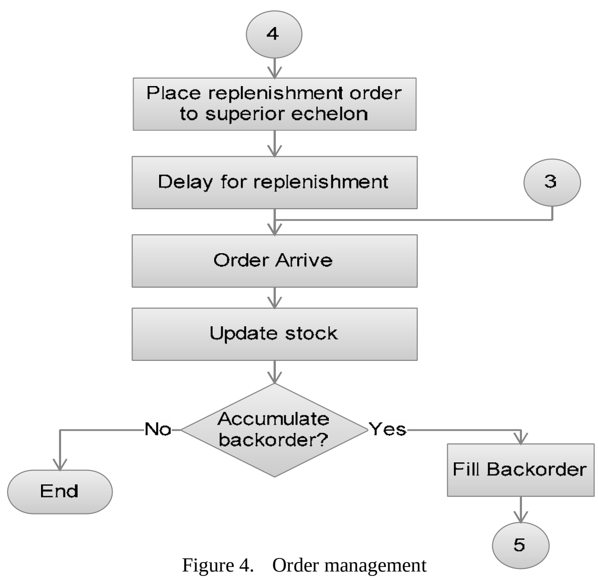

Figure 4. Order management

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 Fig. 5, the retailer and distributor 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.

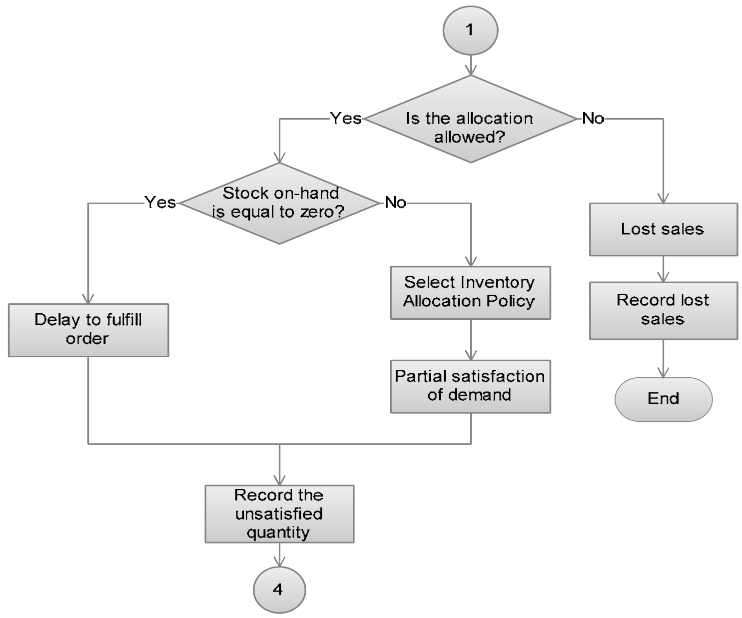

Figure 5. Stock allocation

The Fig. 6 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", "periodic" or "conditionally 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.

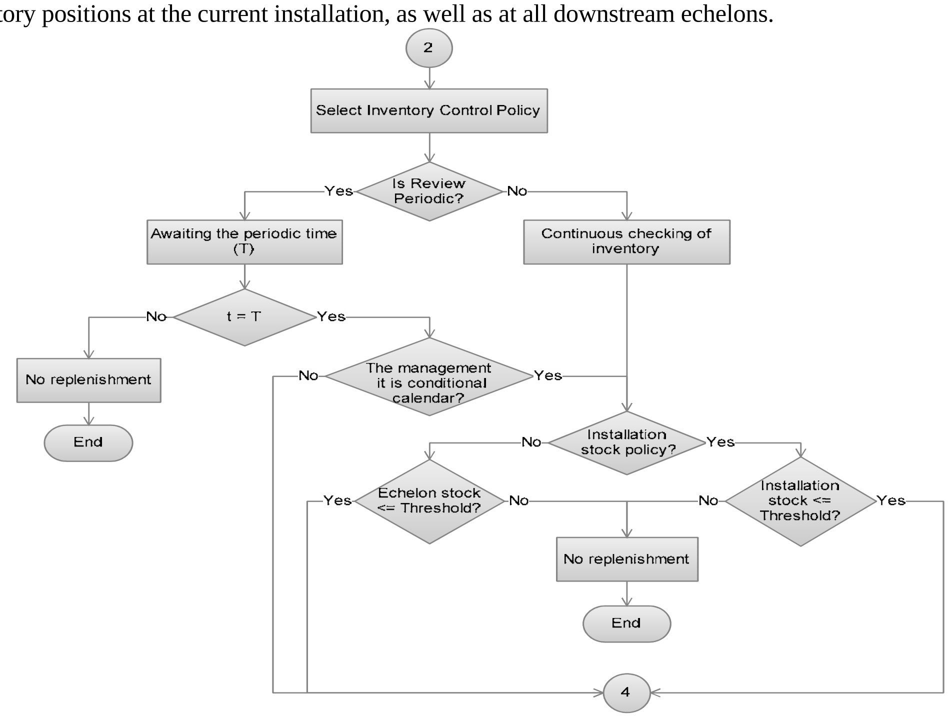

Figure 6. Flow Management Policy [9]

V. Simulation model description

A. Functional view (Use case diagram)

Use case diagrams are excellent to describe the problem domain requirements and communicating with users. There are several kinds of actors in the multi-echelon distribution supply chain. The model developed includes these actors, Fig.7:

- **Customer:** who place orders for finished products, but does not supply any products to any other participants.
- **Distributor:** is the intermediate actor in the supply chain. Distributor both place orders from other participants and deliver orders to other participants. Distributor includes warehouses, distribution center, depot, etc.
- **Retailer:** he is the most downstream participants of the supply chain, receive and satisfy order from the end customer.
- **Supervisor:** control and optimize the entire multi-echelon system.
- **Supplier:** are the most upstream participants of the supply chain. Suppliers supply products to other participants, but do not receive any.
- **Information system:** receive information and send decisions.

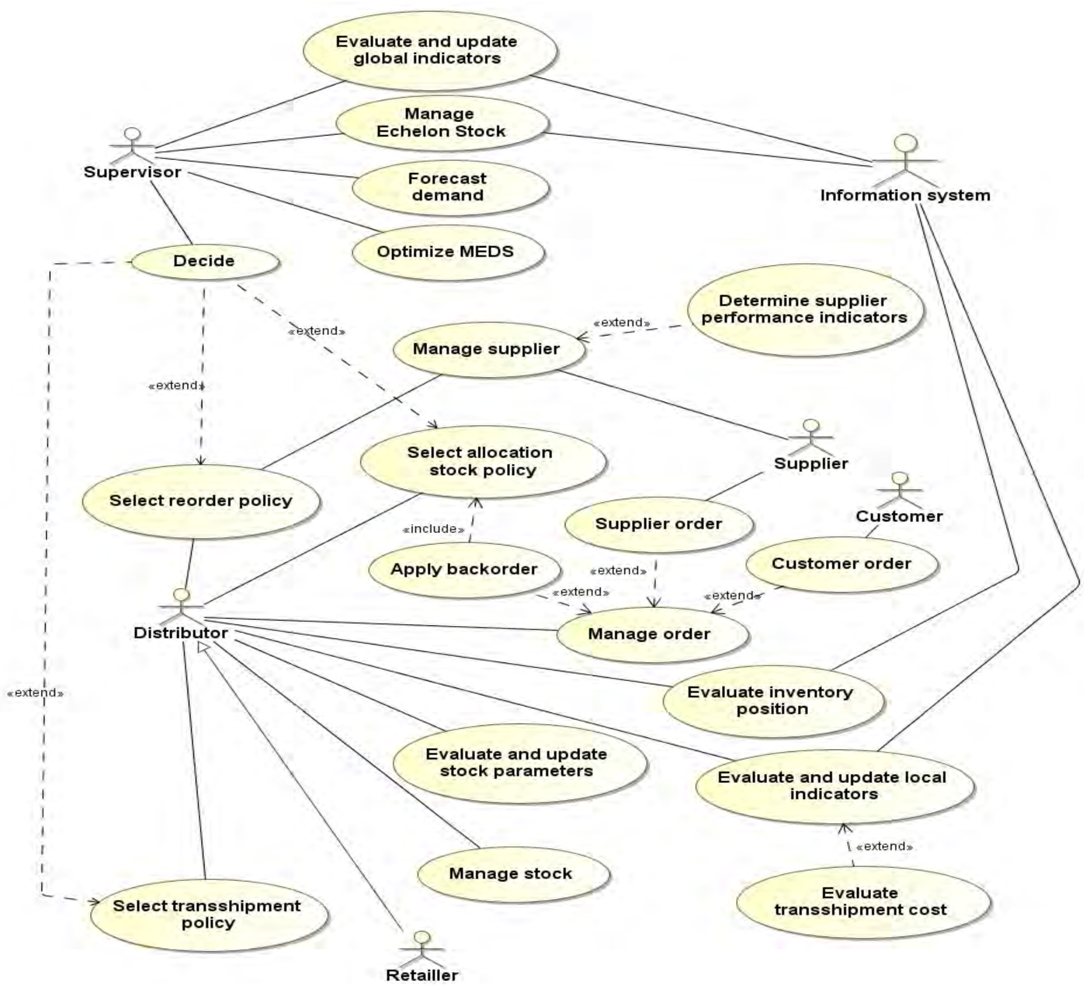

Figure 7. Use case diagram for MEDSC [10]

B. Static view (Class diagram)

The class diagram allows modeling the entities with their internal structure and their relationship to other entities. The class diagram is the most important in object-oriented design. Fig. 8 illustrates that each Node has a products in its stock locations. In Node, each stock is unique because it only keeps track of inventory status for a product such as on hand, backlog, inventory position, etc. For example, a supplier supplies a product to a manager. An OrderMangment is a group of orders that have been commissioned for supply from a Node or suppliers. In addition, an order requires having a supplier and a customer and a manager reference. Figure 7 indicates that the order has multiple relationships. A node can make many orders. Once a supplier is capable of filling an order, its stock will make a shipment that contains the demanded products. These three supply chain (supplier, customer and manager) elements are the entities that flow around the chain.

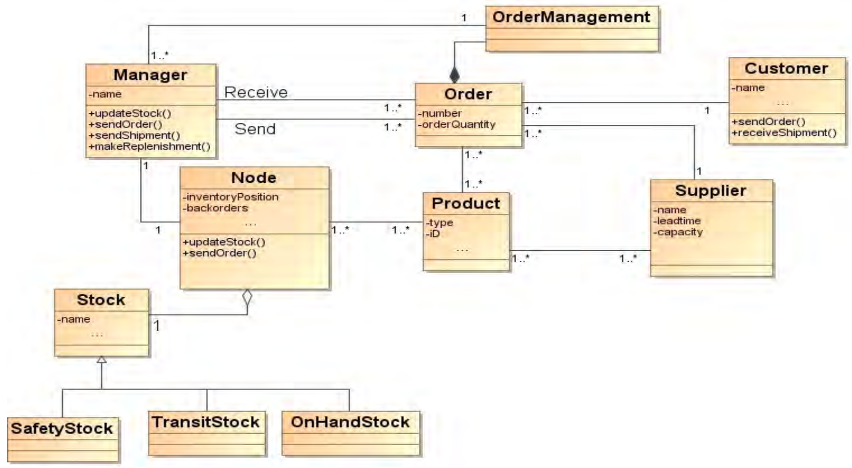

Figure 8. Order management

MEDSC is a complex system of interconnected network nodes that exchange material and information in order to provide material, products, or services to end-users. This conceptual network has a set of Nodes and Echelons. A Node in this MEDSC can represent a Warehouse, CDC, or RDC. In Fig. 9, each Node may have many relationships with another Node. A Class Association BetweenNode represents a conceptual connection between Nodes and indicates the possible flow of information or material between them. Within the MEDSC, each relationship is a unique conceptual connection because this connection indicates that a supplier supplies a customer with a specific product. The three classes (Echelon, Node, BetweenNode) form a unique connection to identify a Node. In Fig. 8, aggregation is used in this model to achieve the containment of Nodes in Echelon network and Echelon in MEDSC. From this model structure, a customer (Downstream) and a supplier (Upstream) may know who their suppliers and customers are. Therefore, they know to send orders to their suppliers and to send shipments to their customers.

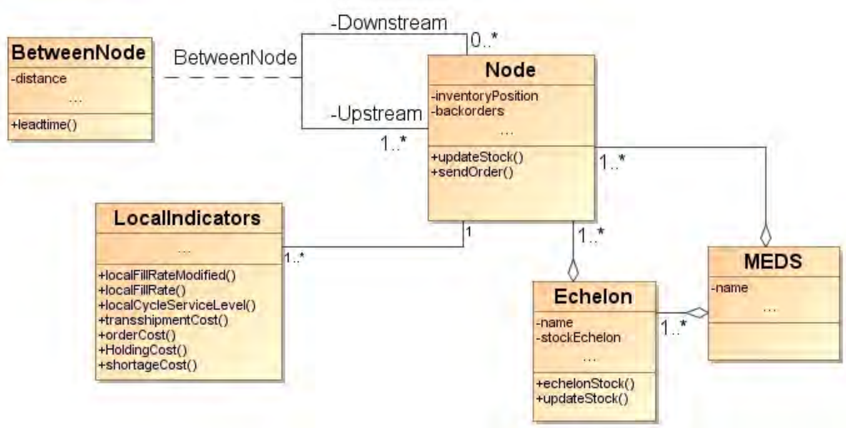

Figure 9. System structure

In the system control we represent a relational structure between organizational decision centers. We distinguish two types of decision centers: centralized system and decentralized decision centers. In Fig. 10, the centralized system control centers can make decision in the different horizons of the system. The relation between these centers can be hierarchical or at the same level. The decentralized decision centers can represent the decisional processes of autonomous processes.

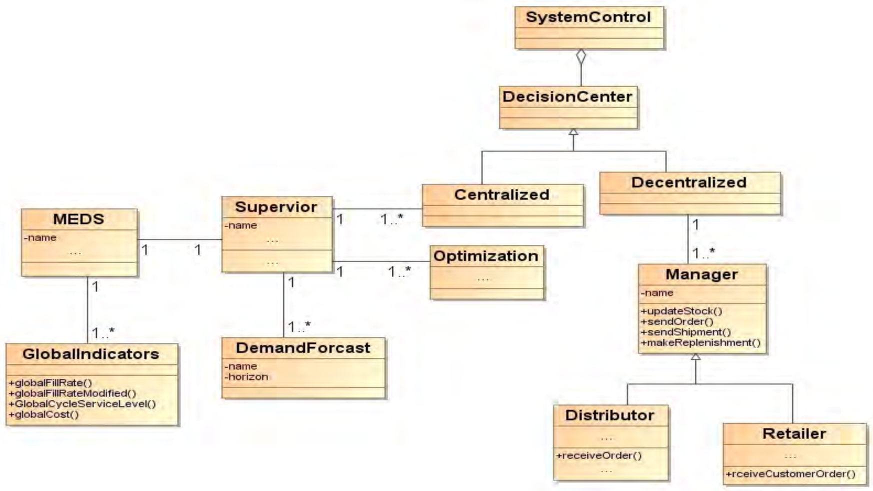

Figure 10. System control

Inventory management policies (Allocation policies, inventory control policies and transshipment policies) allow the encapsulation of rules to control the associated inventory. In the Fig.10 every Node class 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 InventoryControlPolicy class 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 AllocationStockPolicy class allows choosing the policy to satisfy partially an order, in case of exceed demand, and the class transshipmentPolicy allows choosing the strategy or the rules to share the stocks in the same echelon.

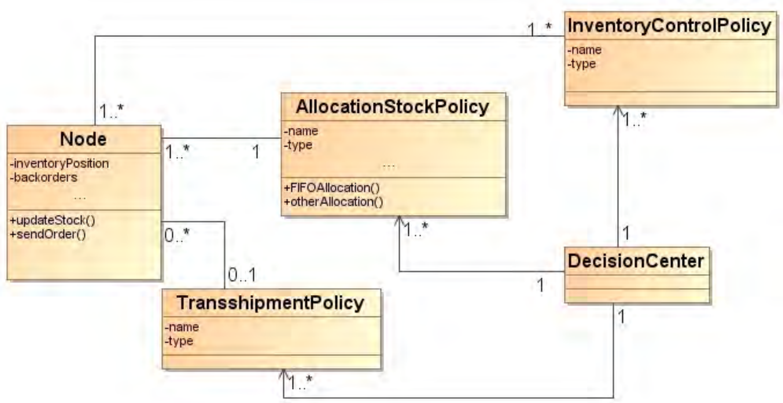

Figure 11. Inventory management policies

C. Dynamic view

1) Sequence diagram

Sequence diagrams describe how objects interact and communicate with each other. The sequence diagram of Fig. 12 shows the various exchanges that occur between the supervisor, the information system and node. Moreover, the calculation of the global indicators requires knowledge of local indicators of all existing nodes in the network, hence the important role of information system. This allows the exchange, storage, and data consolidation. Besides the assessment of global indicators, there is inventory valuation level, system optimization and demand forecasting.

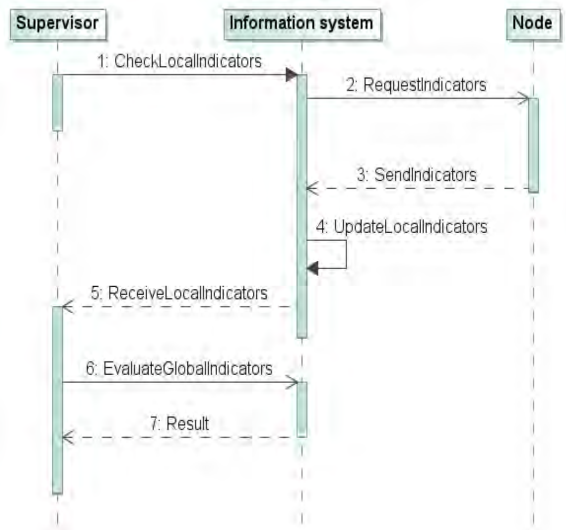

Figure 12. Sequence diqgram "Global indicators"

Fig. 13 illustrates the set of messages exchanged to submit an order. Where a costumer places an order and checks the lead time and cost incurred by it, its part of the retailer to check the availability of stock and send the evaluation of time and cost to the customer. The shipment of the order needs the confirmation of the retailer.

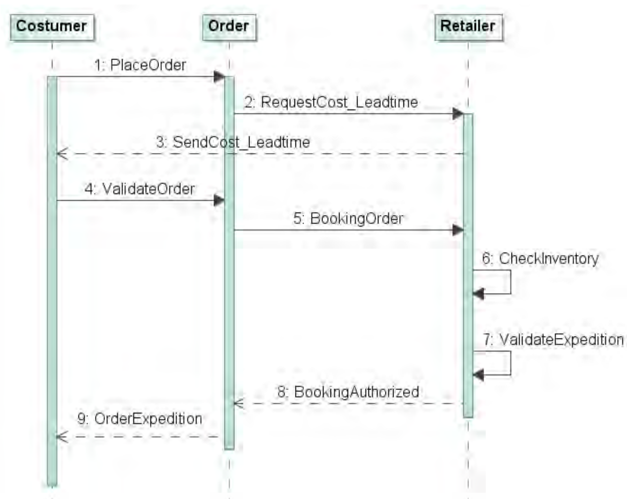

Figure 13. Sequence diagram "New order"

2) State chart diagram

State diagrams describe the possible states a particular object can get into. Fig. 14 illustrates the states of stock; in this case the stock may have different states:

- Transit stock: all outstanding orders to one node.
- On hand stock: the available products in the inventory.
- Backorder: quantity of unsatisfied demand.
- Safety stock: quantity of product stored to meet excess demand.

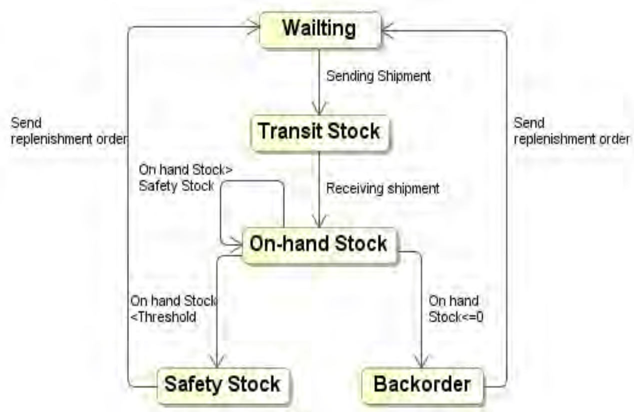

Figure 14. State diagram “Stock”

Fig. 15 shows the states of order management. The order is met directly if on hand inventory is sufficient; otherwise a replenishment order is send to fulfill the demand.

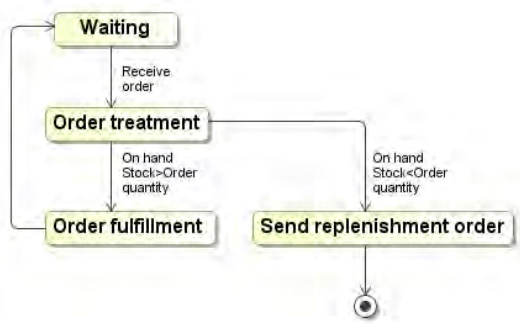

Figure 15. State diagram “Order”

VI. DISCUSSION

The model under consideration, conducted through the use of simulation, this model was developed representing different issues of MEDSC. We have selected UML, which has a well-defined semantics, to assist us to model the MEDSC. The UML provides a clarified spectrum of notations for representing different aspects of the system. This research is part of a larger effort to develop an object-oriented framework for simulating the MEDSC.

A framework to model multi-echelon inventory systems, with options and flexibility to model each point in the network with unique behavioral characteristics, we made this by describing the object-oriented constructs by illustrating their use in simulating multi-echelon inventory systems. The findings of this paper are important to academics and practitioners. For the analysis and conceptualization of the MEDSC, we summarize the major configurations of this system captured in the literature review.

In this paper we did not provide a complete discussion of all of the implementation details of all classes, instead we provide enough details on the important classes along with their essential behaviors in order to illustrate their use as well as their functionality. In addition, it should be known that a variety of complex systems can be modeled at each echelon and at each node, as well as for each item type a variety of inventory policies, allocation stock policies, and demand configurations. Furthermore, because the framework is object-oriented, we can use the usefulness of the object-oriented modeling to develop additional models and behaviors of the MEDSC, or to combine it with other logistics’ systems.

VII. CONCLUSION

Several strategies of flow management and inventory control of the MEDSC have been proposed in the literature. Currently, it becomes difficult to determine how each company must configure its strategies, taking into account the constraints and the special features. The simulation approach was made to evaluate these various options and their impacts on the multi-echelon system. In this paper, we have analyzed the issues of the multi-echelon distribution supply chain, whereby all elements of this chain and their interconnections characterized by the dynamic aspect; and where there are the random events at each node of the network. Also, we have proposed a generic simulation model that can be adapted to different configurations of multi-echelon network, and allows the evaluation of its performance.

In the future research, we will target the following goals: The first one is to give a more formal setting for this approach in order to propose a simulation platform. The second one, deals within the scope of our research team, this scope concerns the optimization of the multi-echelon distribution system. For this matter, we will use the discrete event simulation software.

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