Simulation Models for Multi-echelon Inventory Management Problem: A Literature Review

Nouçaiba Sbai and Abdelaziz Berrado
Equipe AMIPS
Ecole Mohammadia d'Ingénieurs
Mohammed V University in Rabat
Morocco
noucaibasbai@research.emi.ac.ma, berrado@emi.ac.ma

Abstract
Inventory management is a fundamental lever of supply chain management. Through effective inventory management, companies can prevent high levels of inventory while providing a good customer service level. With the increased complexity of the supply chain nowadays, multi-echelon inventory management has become a challenging and interesting research area. In particular, it considers the entire system as a whole which allows for managing the interdependencies between different stages of the supply chain. Today, solving the multi-echelon inventory management problem with analytical models is not sufficient anymore. Numerous researchers developed simulation models to overcome the restrictions of mathematical modeling and to reflect the dynamic behaviors of different parameters involved in multi-echelon inventory systems. This paper provides insights into the use of simulation modeling to assist in making multi-echelon inventory management decisions. A classification of several simulation models of multi-echelon inventory systems according to a set of features used by the literature is established as well.

Keywords
Multi-echelon inventory systems, Simulation, Supply chain management, Inventory management

1. Introduction
Nowadays, managing inventories is becoming an important issue in supply chain management. Minimizing inventory levels across the entire system while providing a good customer service level presents always a difficult tradeoff. Research in multi-echelon inventory management is improving recently due to the increased complexity of the supply chains.

In a multi-echelon inventory system, different facilities are connected through information and material flows which makes controlling inventory very crucial and difficult. Managing inventory in each installation without taking into consideration other sites' inventory cannot always yield good results. For this reason, multi-echelon inventory policies aim to provide an overall integrated approach to managing inventory. Those policies are mainly focused on increasing product availability and lowering costs (Patil et al., 2011).

Researchers are constantly looking for solutions to model complex supply chains and control the flows of goods through multiple sites belonging to the same system. Clark and Scarf (1960) is an early work to investigate multi-echelon inventory models. After that, as explained in (Sbai and Berrado, 2018), several researchers explored and contributed to advancing this research area.

Establishing interdependence relations between decision parameters of different processes of the supply chain cannot be easily modeled analytically. However, modeling dynamic networks can be possible and flexible through simulation (Dong, 2001). It provides an effective evaluation tool for supply chain performance and risks. The simulation model can provide details about the dynamic and stochastic inventory system with accuracy (Chu et al. 2015).

Although many authors developed simulation models to evaluate the related multi-echelon inventory systems performance, an updated literature review of the use of simulation modeling in multi-echelon inventory management is yet to be established. For this purpose, we intend in this paper to provide insights into the simulation in multi-echelon inventory systems. Besides, we elaborate on a classification of several simulation models for multi-echelon inventory systems according to features used in the literature.

This paper is organized into four sections. In the next section, we present related work to simulation modeling in multi-echelon inventory management. We elaborate in section 3 a classification of simulation models according to features used in the literature. In the last section, we determine the simulation specifications for multi-echelon inventory management problem.

2. Simulation in multi-echelon inventory management: Problem definition and related work

2.1 Overview of multi-echelon inventory management problem

A multi-echelon inventory system is composed of multiple levels that are grouped into echelons. In particular, an echelon may contain production or distribution sites as well as products in-process activities. Inventories may exist as finished goods, raw materials, or subassemblies through the entire supply chain (Gümüs and Güneri, 2007). We present in Figure 1 an illustration of a multi-echelon inventory system.

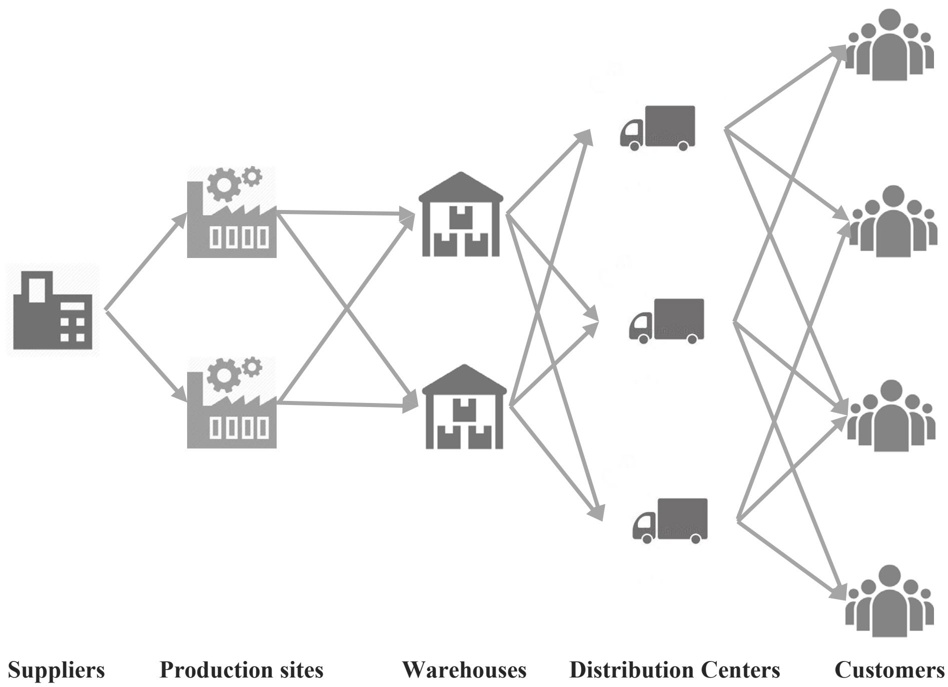

Figure 1. A multi-echelon inventory system illustration

Many characteristics of the multi-echelon inventory system make it present numerous challenges in supply chain management. Firstly, physical locations with multiple stocks are involved in the same system. Moreover, due to high levels of inventory that may be carried in different stages, managers may face multiple tradeoffs like lowering stocks and increasing the responsiveness of the supply chain (Vrat, 2014).

There are four structures of multi-echelon inventory systems: serial systems, distribution systems, assembly systems, and general systems (Axsäter 2015). In the first one, an installation had only one supplier and one customer. In a distribution system, a facility may have multiple successors but only one supplier for each customer. The assembly system is characterized as a convergent system in which multiple components can be assembled into one item. Finally, the general structure can contain any of the previous three types as a part of the whole system.

Generally, finding an optimal control policy for a multi-echelon inventory system is complex. Making a replenishment order for an installation may depend on other's sites inventory status. For this reason, researchers tried to develop inventory policies to find solutions for managing stocks in multi-location supply chains. Admittedly, four major policies are applied for multi-echelon inventory management : (i) replenishment policies (continuous review policy or periodic review policy), (ii) ordering policies (installation stock ordering policy or echelon stock ordering policy), (iii) lot sizing (choosing batch quantities), and finally (iv) safety stock allocation policies (Axsäter 2015).

Undoubtedly, inventory management presents an important lever of multi-echelon supply chains. Recently, controlling multi-echelon inventory systems became possible due to the development of information technologies and the increase in research efforts in this domain. Consequently, simulation can be applied successfully to define optimal policies as well as evaluating the overall performance of the supply chain.

2.2 Relevance of simulation for multi-echelon inventory management problem

In the present time, evaluating performance indicators and decision variables through analytical methods is becoming more complex because of the uncertainties and nonlinearities involved in current multi-level supply chain networks (Noordhoek et al. 2018). Fortunately, the simulation method is capable of modeling complex systems with complicated flows between different nodes.

Two strong techniques are combined in simulation: conceptual modeling and simulation. Conceptual modeling allows the modeler to represent “the real system” and understand the background of the problem situation. The simulation will help next to conduct a simplified representation of the system (Robinson, 2014). The use of simulation allows us to characterize the stochastic behavior of multi-level networks to make future forecasts or to assess the performance of the entire system. Simulation methods can capture not only system uncertainties but their dynamic and time-variant behaviors as well. Consequently, a lot of researchers consider simulation modeling one of the best methods to use for analyzing supply chains.

The aim of simulating a multi-echelon inventory system is to evaluate the network performance parameters that correspond to a given scenario. Simulation can deal with the nature of supply chain systems. Multi-level inventory systems are interconnected and face variability as well as complexity. Simulation models allow for representing the variability and interconnectedness of a system. Thus, it becomes feasible by using simulation to predict system performance, to conduct a comparison of alternative network designs, and to determine the impact of each inventory policy on the overall system performance (Robinson, 2014).

2.3 Literature review of simulation models for multi-echelon inventory systems

Many authors investigated the multi-echelon inventory management problem using mathematical inventory theory. However, the models proposed were oversimplified with numerous assumptions to cope with the real problem situation. Fortunately, simulation can be conducted to represent more realistic models (Chu et al. 2015). Many elements can be considered in the simulation models such as inventory policies, system structure, and general specifications related to the nature of the supply chain.

The literature on supply chain simulation includes various product categories and multiple ordering policies in numerous industries. To study the impact of various inventory control policies, Towill et al. (1992) used simulation as a tool for evaluation. Lee and Billington (1993) evaluated alternatives by developing a supply chain model for HP. In their research paper, Strader et al. (1998) used multi-agent simulation as a method to find out the impact that has information sharing on order fulfillment in distribution/assembly supply chains. Performance evaluation of conjoined supply chain behavior was elaborated by Beamon and Chen (2001). Holweg and Bicheno (2002) demonstrated how a simulation model can lead to possible improvements for a supply chain. Van der Vorst et al. (2000) modeled food supply chains' dynamic behavior and evaluated the potential benefits of alternative designs of the supply chain by using discrete-event simulation.

Multiple research works studied simulation in multi-echelon inventory management. Köchel and Nieländer (2005) proposed a simulation-optimization approach to overcome restrictions related to analytical models. The authors used a simulator combined with a suitable optimization method. Daniel and Rajendran (2005) studied a single-product serial supply chain. The authors suggested a genetic algorithm (GA) to optimize the inventory policy used (base-stock policy) while minimizing overall costs. The base stock level resulted from the GA was evaluated using simulation. Rossetti et al. (2007) discussed the design and implementation of an object-oriented framework for multi-echelon inventory systems simulation. They built the framework on a Java Simulation Library (JSL). A simulation model for a multi-echelon inventory management problem was developed by Wan and Zhao (2009). The authors used Arena for the simulation model to determine the reorder point and batch size for the most downstream stage (retailers) while reducing the overall costs of the entire system.

The simulation research in connection to the multi-echelon inventory management problem has increased in the last decade. Patil et al. (2011) built a simulation model using Arena 7.0 to improve sales and reduce lost sales for a multi-echelon inventory system composed of one distribution center, three retailers, and a customer. A multi-echelon inventory control model was developed by Zhou et al. (2013). The authors applied the joint replenishment strategy and used the Genetic Algorithm to find a solution for the model. A simulation of the suggested model under three ordering strategies is provided in this paper. Attanayake et al. (2014) developed an inventory optimization system for the healthcare industry. A simulation model is designed with (s, S) policy and allows for minimizing the inventory costs. The paper of Tsai and Liu (2015) presented a simulation-based decision support system for the multi-echelon inventory management problem. The authors aimed to determine optimal stocking levels to reduce inventory costs. The decision support derived algorithms can be used in different scenarios. Chu and You (2014) developed a simulation-based optimization framework for distribution inventory systems optimization. The different installations involved in the system are controlled with (r, Q) policy. The paper aimed to minimize inventory costs while satisfying settled service levels. Chu and You (2014) simulated a distribution inventory system by an agent-based system. (R, Q) inventory policy was used in different facilities and the objective of the study was to reduce inventory-related costs while maintaining the fill rates. In their study, Zhou et al. (2016) simulated the supply chain of a company to improve its practices. The simulation model was developed as a multi-product multi-echelon supply chain that aimed to determine the different challenges of the company. Montarelo et al. (2017) suggested a simulation-based optimization framework for a case of a four-echelon linear supply chain. The approach was based on a dynamic tabu search metaheuristic. A simulation analysis was implemented by Yan and Liu (2018) to compare single, two, three, and four echelon inventory transsshipments models at different stages. The results of the study showed a decline in the average stock level. Noordhoek et al. (2018) developed a simulation-optimization method to optimize (s, S) inventory policies in a multi-echelon distribution network with fill rate constraints. In their research paper, Abidi et al. (2018) investigated a multi-echelon multi-product pharmaceutical supply chain and presented a system dynamics simulation inventory management model. The objective of the study was to aid the pharmaceutical supply chain sites to choose the appropriate operational service levels while considering the overall cost. Eddoug et al. (2018) evaluated the impact of different distribution management policies on the overall costs and service level of the entire system. The authors developed a discrete event simulation framework to assess different scenarios. The research paper of Xu et al. (2019) involved a simulation-based optimization model for fresh agricultural products of a multi-echelon supply chain. The model was performed by Flexsim simulation software. The results of the simulation are able to provide guidelines and decision aid for solving complex systems and formulating inventory control policies.

3. Classification of simulation models for multi-echelon inventory systems

As can be seen, the history of developing simulation models for multi-echelon inventory systems is still not very large. We provide in the present part a summary of relevant and recent simulation models developed for multi-echelon inventory management problem.

In Table 1, we classified numerous simulation models for multi-echelon inventory systems that were developed by researchers. Based on multiple aspects considered in multi-echelon inventory management as well as those mentioned in the papers as elements of simulation models, we chose the following features that were assumed necessary for the authors in their models' formulation:

- System structure: serial, distribution or assembly system
- Scenarios simulated in the literature: Simulation of an inventory control policy, Study of the relationship between service level and inventory costs, Comparison of inventory transshipment models, Simulation of the overall inventory costs, Comparison of replenishment policies, Simulation of interrelationships among retailers.
- Assumptions: demand-type, product, lead time,
- Evaluation performance indicators: inventory costs, service levels, transportation costs, inventory levels, lost sales.
- Conceptual model: logic flow, process flow, UML.
- The simulation method used: Discrete Event Simulation, Agent-Based simulation

Table 1. Classification of simulation models for multi-echelon inventory systems according to features used in the literature

Features/ Scenarios simulated		Simulation of an inventory control policy	Study of the relationship between service level and inventory costs	Comparison of inventory transshipment models	Simulation of the overall inventory costs	Comparison of replenishment policies	Simulation of interrelationships among retailers
Network structure	Serial system	(Daniel and Rajendran 2005), (Köchel and Nieländer 2005)	(Abidi et al. 2018)	(Yan and Liu 2018)	(Montarelo et al. 2017)		
	Assembly system	(Zhou et al. 2016), (& and Nieländer 2005)				(Zhou et al. 2013)	
	Distribution system	(Xu et al. 2019), (Eddoug et al. 2018), (Chu and You 2014), (Wan and Zhao 2009), (Rossetti et al. 2007), (Köchel and Nieländer 2005)	(Abidi et al. 2018)	(Yan and Liu 2018)	(Noordhoek et al. 2018)	(Zhou et al. 2013)	(Patil et al. 2011)
Assumptions	Stochastic demand	(Xu et al. 2019), (Eddoug et al. 2018), (Noordhoek et al. 2018), (Zhou et al. 2016), (Chu and You 2014), (Attanayake et al. 2014), (Wan and Zhao 2009), (Rossetti et al. 2007), (Daniel and Rajendran 2005)	(Abidi et al. 2018)			(Zhou et al. 2013)	(Patil et al. 2011)
	Deterministic demand	(Montarelo et al. 2017)					
	Stochastic lead time	(Eddoug et al. 2018), (Chu and You 2014), (Attanayake et al. 2014), (Wan and Zhao 2009), (Daniel and Rajendran 2005)					(Patil et al. 2011)
	Deterministic lead time	(Xu et al. 2019), (Noordhoek et al. 2018), (Daniel and Rajendran 2005)			(Montarelo et al. 2017)	(Zhou et al. 2013)	
	Single product	(Noordhoek et al. 2018), (Attanayake et al. 2014), (Wan and Zhao 2009), (Daniel and		(Yan and Liu 2018)	(Mon\tarelo et al. 2017)		(Patil et al. 2011)

		Rajendran 2005), (Köchel and Nieländer 2005)					
	Multiple products	(Xu et al. 2019), (Eddoug et al. 2018), (Zhou et al. 2016)	(Abidi et al. 2018)			(Attanayake et al. 2014)	
Evaluation performance parameters	Inventory costs	(Eddoug et al. 2018), (Noordhoek et al. 2018), (Chu and You 2014) , (Attanayake et al. 2014), (Wan and Zhao 2009), (Daniel and Rajendran 2005), (Köchel and Nieländer 2005)				(Zhou et al. 2013)	
	Service level	(Eddoug et al. 2018), (Noordhoek et al. 2018), (Zhou et al. 2016), (Chu and You 2014), (Attanayake et al. 2014), (Wan and Zhao 2009)		(Yan and Liu 2018)	(Montarelo et al. 2017)	(Zhou et al. 2013)	
	Transportation costs	(Eddoug et al. 2018), (Attanayake et al. 2014)				(Zhou et al. 2013)	
	Inventory levels		(Abidi et al. 2018)	(Yan and Liu 2018)			
	Lost sales						(Patil et al. 2011)
Conceptual model	Logic flow diagram	(Xu et al.2019), (Rossetti et al. 2007)					(Patil et al. 2011)
	Process flow diagram		(Abidi et al. 2018)				
	UML	(Eddoug et al. 2018)					
Simulation method	Discrete Event Simulation	(Eddoug et al. 2018), (Noordhoek et al. 2018), (Attanayake et al. 2014), (Wan and Zhao 2009)			(Montarelo et al. 2017)		
	Agent-Based Simulation	(Chu and You 2014)					

- Simulation tool : Flexsim (Xu et al. 2019), ARENA (Eddoug et al. 2018) ,(Wan and Zhao 2009) and (Patil et al. 2011), iThink SD Software (Abidi et al. 2018), Vensim (Yan and Liu 2018), ExtendSim (Zhou et al. 2016), SIMUL8 (Attanayake et al. 2014), MATLAB (Zhou et al. 2013), Java Simulation Library (JSL) (Rossetti et al. 2007) , KaSimIR (Köchel and Nieländer 2005).

4. Simulation specifications for multi-echelon inventory management

Today, supply chain networks are becoming more complex which makes the application of analytical approaches inaccurate to model real-world systems. With the use of simulation, the actual stochastic and dynamic features of multi-echelon inventory systems can be captured and modeled. In this section, we propose an approach for multi-echelon inventory management simulation modeling. We list different simulation methods used by the literature as well.

4.1 Suggested approach for multi-echelon inventory management simulation modeling

The work of Robinson (2014) defined necessary specifications that should be involved in a simulation study: Background to the problem situation, the simulation study goals, expected benefits, the conceptual model, scenarios to be tested in the experiment, and data requirements.
In this section, we are going to determine the basic steps of a suggested approach for multi-echelon inventory management simulation modeling.

Step 1: Background to the problem situation:
The first step to do before a simulation is to understand the problem situation. An appropriate model is used to describe the real problem. In particular, we need to determine the multi-echelon inventory system structure, demand-type, and inventory policies used to control stocks across the entire system.

Step 2: The simulation study goals:
In this phase, the modeler needs to define the main objectives of the simulation. In other words, the parameters to be considered to validate the model and to judge whether the study has succeeded or not must be identified. While formulating the goals, we should answer to an important question: "what do we want to achieve by the end of our simulation study?"
To answer this question, we consider three elements:

(i) The managers' aim: increase profit, reduce costs, or improve customer service level.
(ii) The level of performance to be used: maximize fill rate/product availability, minimize inventory costs of the whole system, and improve the CSL (customer service level) or other performance variables that are required to quantify the objective of the simulation.
(iii) The constraints: the budget allocated, transportation modes, delay tolerated by customers, and so on.

Step 3: The expected benefits
While simulation can be performed without any kind of risks, it can be used to encourage creativity for problem-solving. For example, managers can use simulation as a decision aid tool to compare many inventory policy alternatives and choose the appropriate one that corresponds to their preferences. More than that, simulation can be beneficial to prove the validity of a typical multi-echelon inventory management policy and convince managers to adopt it by visualizing results through a simulation model.

Step 4: Building the conceptual model for a multi-echelon inventory system
As defined earlier, a conceptual model is drawn to represent the "real system" before going through the simulation model. Wang and Brooks (2007) listed the five most used tools of conceptual model representation for a problem situation.

- Component List: A list of the components to be considered in the model is provided. A brief description of each one is included in more detail.
- Process Flow Diagram: The components of the system are shown as a sequence and involve details for the model.
- Logic Flow Diagram: The model is represented by standard flow diagram symbols to show the logic of the model.
- Activity Cycle Diagram: This diagram can especially be used for discrete-event simulation models (Robinson, 2014).

After choosing a method for designing the conceptual model, the modeler needs to list all assumptions and simplifications related to the problem situation to be simulated. In particular, for the case of multi-echelon inventory management problem, we can specify as assumptions the type of the network structure, the inventory control policy used by installations, the fill rate, unsatisfied demand is backordered or not, order processing times, and other assumptions that could be assumed for the problem situation. Also, simplifications for the model need to be mentioned. As an example, setup costs and the external supplier infinite stock could be simplifications for a multi-echelon inventory management problem.

Step 5: Experimentation
In this phase, simulation can be used to run a single experimental scenario or to compare multiple alternative scenarios. The simulation study can result in finding an improvement or a solution to the real problem addressed. In our case, we can compare multiple inventory policies for a multi-level supply chain network. Particularly, the work of Ech-Cheikh et al. (2014) compared continuous review policy and periodic review policy to study the impact of demand uncertainty and the variability of the control policy for a multi-echelon distribution supply chain.

Step 6: Data requirements
Data are necessary to run a simulation. Based on the work of (Robinson, 2014), we can derive three types of data requirements for multi-echelon inventory management problem:

- Preliminary data: needed to build a detailed understanding of the problem situation. For example, the flow diagram of the current multi-echelon inventory system, the actual inventory status in installations, and so on. This type of data is generally required for the stage of developing the conceptual model.
- Data for model realization: this concerns the development of the computer model. In other words, we may need specific data on demand patterns, products type, and items processing rules at this stage.
- Model validation data: to ensure that the model designed and simulated is representing the real system accurately, this type of data is important. In particular, a sensitivity test can be used to evaluate the impact of multiple system parameters on model behavior (Yan and Liu 2018). The consistency of the model with the actual problem situation can be determined by the test. An analysis of the parameters' dynamic process can be performed at this stage as well.

4.2 Simulation methods

After underlining the different specifications that should be involved in the simulation study of the multi-echelon inventory management problem, it is important to give an overview of the most used simulation methods in our research area. Examples of works that applied those tools are mentioned in section 3. Four major approaches are used for simulation (Robinson 2014):

- Discrete Event Simulation: one or more entities in a discrete-event system can change state at discrete points in time. This technique is applied to representing queuing systems (Fishman 2013). In particular, inventory systems, manufacturing facilities, transportation networks, and many other fields use this method to evaluate the overall performance of their system in terms of orders delay, resource utilization, and so forth.
- Monte Carlo Simulation: the modeler builds a mathematical model that simulated the real system. The approach is based, as in random sampling, on executing the model several times. Random variations are generated on each input variable for each sample. Computations are run through the model that produces random results on each output parameter. This is because every single input is random (Thomopoulos 2013).
- System dynamics: the principle behind system dynamics is that it represents a continuous approach for simulation, describing the situation as a collection of stocks and flows. Stocks are accumulations, namely, products and customers. Flows change the amount of stock with inflows that increase the stock and reduce the outflows (Robinson 2014).
- Agent-Based Simulation (ABS): a modeling and computing approach which simulates dynamic processes involving autonomous agents. A defining feature of this framework is that it allows us to model a population of autonomous agents with their unique characteristics and behaviors that interact broadly. An agent-based model has three important elements: (i) agents, characterized by their behaviors, (ii) agent relationships, which define the methods of interaction and connection, (iii) environment of agents, where agents exist and interact (Macal and North 2014).

4.3 Definition of the problem of selecting and validating the appropriate multi-echelon inventory system through simulation modeling

As can be seen from Table 1, many researchers have developed models for simulating inventory control policies in multi-echelon inventory systems, some other authors compared replenishment policies or studied the relationship between inventory parameters. However, none of the existing models have been used to select and validate the suitable inventory policy for a given multi-echelon supply chain.

Nowadays, decision-makers are looking for guidelines to choose the best inventory policies to adopt for their supply chains. In this context, we intend in our future work to develop and implement a policy for simulation modeling that will help decision-makers select and validate the appropriate multi-echelon inventory system that corresponds to their preferences. A comparison of different multi-echelon inventory system alternatives with the use of simulation will be established.

Conclusion

In the present time, simulation can be an efficient tool for modeling and controlling inventories in multi-echelon supply chains. In this paper, we determined simulation specifications in a multi-echelon inventory management problem. We presented a literature review on simulation models for multi-echelon inventory systems. A classification of several simulation models developed by researchers recently was provided. The models were classified according to a set of features used in the literature. System structure, assumptions such as demand-type and lead time, evaluation parameters, and others, are all important features and relevant elements that should be considered for simulating a multi-echelon inventory system.

Lastly, the literature review on simulation modeling in multi-echelon inventory management presented in this paper will be helpful to build a framework for simulating and comparing different multi-echelon inventory system alternatives to guide decision-makers to choose and validate the appropriate multi-echelon inventory policies that correspond to their preferences and fit to their networks. This could be treated in our future work.

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Biographies

Sbai Nouçaiba is a fourth-year Ph.D. student in Engineering Sciences and Supply chain management in EMI School of Engineering at Mohamed V University in Rabat. She is a member of the Analyze, Modelling, and Integration of Processes and Systems (AMIPS) research team in EMI. Her doctoral main research investigates multi-echelon inventory management with a special focus on sizing multi-echelon inventories in the pharmaceutical sector. Her research interests are in the areas of supply chain management, simulation in supply chain networks, and multi-criteria decision making. She published several conference papers and participated in international conferences in Morocco as well as Europe. She holds an engineering degree in Industrial Engineering from the EMI School of Engineering at Mohamed V University in Rabat.

Dr. Abdelaziz Berrado is a Professor and Chair of Industrial Engineering at the EMI School of Engineering at Mohamed V University in Rabat. He holds a Ph.D. in Decision Systems and Industrial Engineering from Arizona State University and an M.S. and a B.S. /M.S. from San Jose State University and Ecole Mohammadia d'Ingénieurs school of Engineering, respectively. His research and teaching interests are focused in the areas of Data Science, Industrial Statistics, Operations and Supply Chain Modelling, Planning and Control with applications in healthcare systems and other industries. He focuses on developing frameworks, methods, and tools for systems diagnostics, optimization, and control with the aim of operational excellence. Dr. Berrado's work has led to several research papers and conference articles with local and international funding. In addition to academic work, he interacts with different Industries in the areas of Performance Management, Operations and Supply Chain Management, Machine Learning, and Quality Engineering. He reviews for many journals and is a member of INFORMS, IEOM, and IEEE. Previously, he was a senior engineer at Intel
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