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Multi-echelon Inventory System Selection: Case of Distribution Systems

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Abstract

Inventory management presents numerous challenges for many supply chains as they are becoming more complex and composed of multiple stages. Using appropriate multi-echelon inventory management policies allows supply chains to deliver the required level of responsiveness efficiently by optimizing inventory levels across the entire network and improving customer service levels. This paper provides a Multi-Criteria Decision Making (MCDM) approach for the multi-echelon inventory system selection problem. The scope of this paper is limited to the case of Distribution systems. The suggested approach identifies for a given supply chain configuration, a set of selection criteria related to supply chain costs and overall responsiveness. These criteria are used to compare and choose the best alternative from different multi-echelon distribution inventory system configurations by using a suitable MCDM method. Eight different multi-echelon distribution inventory system alternatives are generated. Each one is a combination of three main inventory policies: (i) replenishment policies, (ii) ordering policies, and (iii) safety stock allocation policies. The suggested approach is illustrated in the case of the pharmaceuticals products supply chain in the public sector in Morocco. Depending on the decision problem nature and other criteria, the AHP method proved to be the suitable MCDM method for selecting the best multi-echelon inventory system for the Moroccan pharmaceutical products supply chain. The analysis indicates that assigning inventory to the most downstream facilities close to patients and adopting an installation stock ordering policy implemented by a decentralized decision system is the best option for the supply chain considered in the case study.

Keywords: Multi-echelon inventory management; Distribution systems; Multi-criteria decision making; Pharmaceutical products supply chain.

1. Introduction

Supply chain inventory management is an integrated approach to inventory planning and monitoring across the entire network of cooperating entities from the supply source to the end customer. Supply chain inventory management aims to increase customer service, increase product variety and availability, and minimize costs (Gumus et al., 2010). The efficiency of the supply chain requires solid inventory management policies that enable lower excess inventory levels in the overall system (Ekanayake et al., 2016).

Due to the dynamic nature of complex large-scale inventory systems, multi-echelon inventory strategies need to be analysed and applied to establish inventory levels and increase the responsiveness of the supply chain. Multi-echelon system design creates difficulties and challenges due to the need to take into consideration various variables and factors influencing demand and supply fluctuations across the entire supply chain network (Ekanayake et al., 2016).

It is considerably more difficult to manage inventory in a multi-echelon supply chain than to control it in a single echelon one. Most supply chain systems have multiple locations or stages (Shenoy and Rosas, 2018). Optimizing inventory one echelon at a time yields excess inventory without having a considerable improvement in customer service (Gumus et al., 2010). A single-echelon supply chain structure follows a decentralized strategy that allows each node to be responsible for its inventory policy and avoids the fact that interrelationships between nodes create an excess inventory or lower fill rates in the system. A multi-echelon supply chain system, on the other hand, follows a centralized approach that considers inventory optimization holistically through the supply chain network (Ekanayake et al., 2016). For the entire supply chain network, multi-echelon systems have the optimal inventory levels and provide strong results for individual nodes.

Multi-Criteria Decision Making (MCDM) is a powerful technique for integrating decision makers' values and preferences across a variety of criteria, as well as providing useful recommendations that will help with critical decisions. Multi-Criteria Decision Analysis has seen a tremendous amount of use. Its relevance for several application fields has grown dramatically, particularly when new approaches emerge, and current ones improve. A variety of MCDM methodologies have been developed and tested. The observed advantages may be powerful for many fields of study, according to the literature reviewed (Velasquez and Hester, 2013). Multi-Criteria Decision Making is a useful tool in a variety of economic, manufacturing, material selection, supply chain management, project evaluation and selection, and constructional problems. Many approaches to solving multi-attribute decision-making problems have been proposed so far (Gavade, 2014).

Because we must evaluate various criteria relevant to each sub-criterion of the Supply Chain (SC) throughout the whole SC cycle, SCM is an MCDM problem. To manage the SC, we must first determine the relationship between each criterion and how it affects the SC's performance. The decision is made based on the indicators identified. This demonstrates the importance of decision-making in managing the SC cycle and that SCM is an MCDM problem. The competing objectives of maximizing profit and customer responsiveness while reducing supply chain risk are often used to determine supply chain management decisions (Khan et al., 2018).

Researchers have investigated the multi-echelon inventory management problem for more than 50 years (de Kok et al., 2018). Although many authors investigated this area of research and proposed several models for solving multi-echelon inventory management-related problems (Sbai and Berrado, 2018), many decision-makers are still facing challenges and difficulties to select inventory strategies that correspond to their supply chain design and meet their needs in terms of service level and product availability. Thus, it seems important to address the selection and choice of multi-echelon inventory policies for a given supply chain structure. Precisely, selecting the best multi-echelon inventory system policies for distribution systems among numerous alternatives using a multi-criteria decision making (MCDM) method has not been investigated yet in our knowledge. For this reason, we aim in this paper to provide an approach to select and choose the appropriate multi-echelon distribution inventory system that fulfils the needs and preferences of the decision-maker.

The approach proposed starts with a characterization of the current supply chain network. After that, we determine the criteria for selection based on inventory-related issues such as supply chain efficiency and responsiveness. Then, a Multi-criteria decision-making (MCDM) method is chosen by taking into consideration the decision problem characteristics and tool capabilities. Finally, the best multi-echelon distribution inventory system is selected by applying the Multi-criteria decision-making (MCDM) methodology.

Our paper is composed of six sections. The next section presents an overview of multi-echelon inventory management in distribution systems and a description of the work methodology to be followed. After that, multi-echelon inventory system alternatives are generated for the case of distribution systems. The process for constructing the alternatives is explained in detail in this section. Finally, we illustrate the multi-criteria decision-making-based approach proposed by the case of the pharmaceutical products supply chain in the Moroccan public sector.

2. Components of the multi-echelon inventory management problem in distribution systems

2.1 Overview of multi-echelon inventory management in distribution systems

At present, supply chains are looking for efficient control of inventories while minimizing costs related to carrying stocks. While the current networks involve many facilities at different stages, managing each installation individually cannot lead to good results. Due to a large number of entities, the number of parameters, and the stochastic nature of those parameters, such as downstream facilities demand, multi-echelon supply chain problems are more difficult to address than single echelon supply chain issues (Elarbi et al., 2021). A multi-echelon inventory system aims to reduce overall supply chain costs by lowering inventory costs while maintaining a high level of customer service (Das et al., 2017). Consequently, thorough research has been developed by many researchers in a multi-level supply chain area, and different models were suggested as a set of multi-echelon inventory management policies.

A multi-echelon inventory system presents a network where multiple suppliers and multiple customers exchange products and information. Moreover, different stages are gathered into echelons (Scott and Xu, 2017). The inventory of a certain installation added to all downstream installations inventory is considered as the "echelon inventory"(Axsäter and Rosling, 1993).

We focus in this research paper on distribution inventory systems. We illustrate in Figure 1 a distribution inventory system with suppliers, a central warehouse, three distribution centres, four retailers, and several customers. In a distribution network, each downstream facility or installation orders from only one immediate supplier or upstream site (Grob, 2019).

Controlling inventory in a multi-echelon distribution inventory system requires integrated as well as sophisticated methods. Single-echelon policies consider only information related to each installation independently to the inventory status in other stages. The overall supply chain network has high inventory levels and low fill rates as a result of such a micro view of the problem. A multi-echelon inventory structure, on the other hand, allows inventory parameters to be determined simultaneously while taking into account all connected nodes' interrelationships (Ekanayake et al., 2016). Therefore, applying single rules and the lack of coordination between different stages in multi-echelon supply chains may lead to carrying huge inventory levels. For this reason, the call for multi-echelon inventory policies became an interesting research area for many authors.

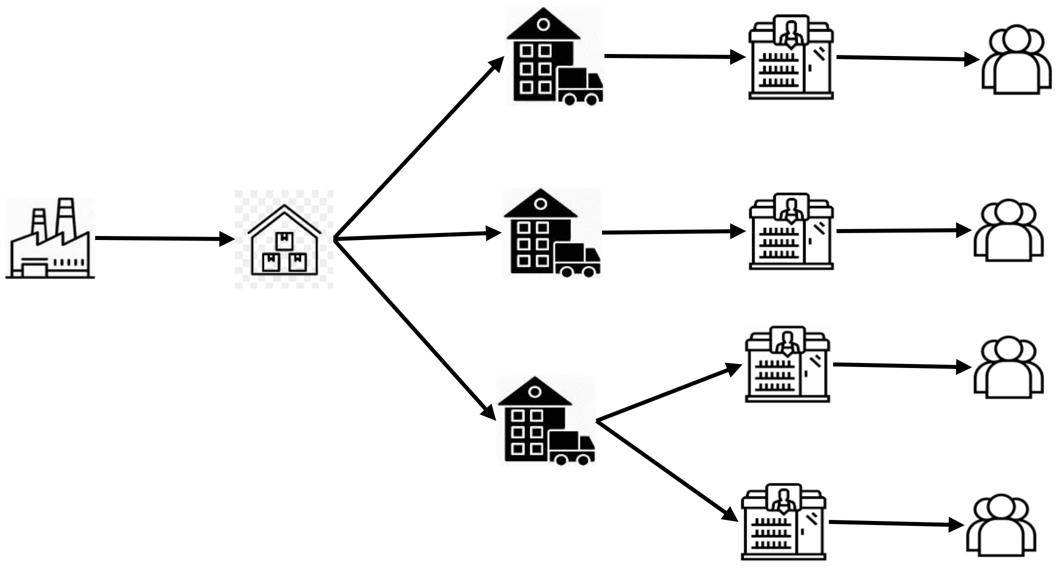

Figure 1. Illustration of a Multi-echelon inventory system: Case of a distribution system

An inventory policy must address two questions: when the inventory position must be checked and what quantity each order should contain (Firoozi, 2018). As we described in a previous work (Sbai and Berrado, 2019) and based on the literature, the most frequently used inventory policies can be classified under four broad categories: replenishment policies (continuous or periodic review policies), ordering policies (installation stock ordering policy, echelon stock ordering policy), lot sizing (batch quantities choice), and finally safety stock allocation policies. In Table 1, we summarize the multi-echelon inventory policies used in the literature for the case of distribution systems.

2.2. Problem statement

In practice, many decision-makers are not capable of choosing the inventory policies that correspond to the configuration of their supply chains and fulfil their needs in terms of the service level and product availability. More than that, multiple trade-offs can challenge managers nowadays. In other words, applying single-echelon methods for each facility is easier but it doesn’t consider the inventory status in other installations. As a result, some sites can suffer from stock-outs and others can carry excess inventory. Consequently, the selection of appropriate multi-echelon inventory policies based on a set of multiple alternatives presents an important issue.

Although many models developed by the literature used combinations of the multi-echelon distribution inventory policies (Clark and Scarf, 1960; Ganeshan, 1999; Guerrero et al., 2013; Moinzadeh, 2002; Tsiakis et al., 2001; Zhou et al., 2013), the decision-makers are struggling to determine the suitable multi-stage methods that will allow them to satisfy their preferences about cost minimization or product availability.

Formulating the best alternatives based on distribution inventory policies while considering the decision-maker preferences expressed as a set of multiple criteria, presents a multi-criteria decision-making situation. Selecting the appropriate multi-echelon distribution inventory system considers the following: modelling the current structure/configuration of the supply chain, making a list of different criteria associated with the inventory-related decisions as well as evaluating the possible options/alternatives with a proper MCDM methodology.

Table 1. Summary of inventory policies *used* in multi-echelon inventory systems: Case of distribution systems

Multi-echelon inventory policies	**Description**

Replenishment policies	**Continuous review policy**	The inventory status in each installation is continuously tracked (Baron et al., 2020). As soon as the inventory position declines to a certain level, an order is placed immediately (Axsäter, 2003).
	Periodic review policy	Reviews of inventory positions are carried out at only certain periods. The "review period" presents the time interval between reviews (Axsäter, 2003).
Ordering policies	**Installation stock ordering policy**	The ordering quantities are based only on the inventory position at an installation. The inventory status in other facilities is not taken into account (Karaarslan, 2012).
	Echelon stock ordering policy	A centralized information system is required for implementing this ordering policy. We consider an "echelon inventory position" while ordering quantities for an installation. It is obtained by adding the installation inventory position to all downstream installations inventory (Axsäter and Rosling, 1993).
Lot sizing		In inventory management, lot sizing decisions balance the cost of placing orders against the cost of keeping inventory (Noblesse et al., 2014). Lot sizing is choosing batch quantities for a multi-echelon inventory system. The choice of a batch quantity for a certain facility is independent of which type of ordering policy the system is adopting (Axsäter, 2015). Due to the dependency between the different levels in the multi-echelon inventory supply chain, determining batch quantities in such a system remains a difficult issue in the literature. Axsäter (2015) proposed for the distribution systems, the "Roundy's approximation" as the best practical inventor policy for fixing batch quantities.
Safety stocks allocation policies		The shortage is a typical occurrence, particularly when the demand is uncertain. When a scarcity occurs, some customers may prefer to accept backorders or buy from another company (Roy et al., 2020). Consequently, safety inventory is considered important for supply chain responsiveness. For distribution systems, Chopra and Meindl (2012) suggested two ways of carrying safety inventory in a multi-echelon distribution inventory system: allocating safety inventory in upstream installations or downstream installations. In a previous work (Logistiqua 2019), we provided a literature review on the most used safety stocks allocation methods developed by researchers.

3. Suggested MCDM based approach for multi-echelon inventory system selection in distribution systems

In a previous work (Sbai and Berrado, 2018), we investigated multiple research papers that treated the multi-echelon inventory management problem. Although many authors developed different models that applied multi-echelon inventory policies to numerous problems, a process for multi-echelon inventory system selection for distribution systems is not yet suggested in our knowledge.

For this reason, we aim to propose an MCDM based approach for distribution inventory system selection. In the present paper, we provide an approach that will guide the decision-makers to choose among multiple alternatives the appropriate combination of multi-echelon inventory policies which are consistent with the current structure of their supply chain networks and in accord with their preferences.

In a previous work (Sbai et al., 2020a), we proposed an AHP based approach for distribution inventory systems. The main purpose of the paper was to use the Analytic Hierarchy Process (AHP) method to choose and select the appropriate multi-echelon inventory system in the case of distribution systems. In this research work, we intend to emphasize more on the generating alternatives process and propose a general MCDM method for multi-echelon inventory system selection with a focus on distribution systems.

The alternatives proposed are going to be based on the multi-echelon inventory policies described in the previous part. We select the best option assuming the DM's preferences in terms of supply chain efficiency and responsiveness. Besides, we will guide DMs to choose the suitable MCDM method/tool to be applied to their decision problem.

Decision-making is tremendously complex when we are called to evaluate multiple alternatives with various criteria (Munier and Hontoria, 2021). Several issues should be considered: the importance of criteria (weights), the decision-maker preferences, and the performance of the alternatives for each criterion (Xu, 2015). Consequently, a sophisticated methodology needs to be developed to overcome those problems.

Recently, many research areas used MCDM techniques such as environment, supply chain management, quality management, technology and information management, and many other fields (Khan et al., 2018). MCDM methods support people to make decisions by ranking alternatives according to a preference order. Therefore, we intend to provide in this part an MCDM based approach for multi-echelon inventory system selection. We will explain each step of the process in detail for distribution inventory systems.

3.1 Presentation of the proposed MCDM based approach for multi-echelon inventory system selection

To aid decision-makers to select the best multi-echelon inventory system from a set of alternatives and considering their preferences, the MCDM based approach illustrated in Figure 2 is suggested.

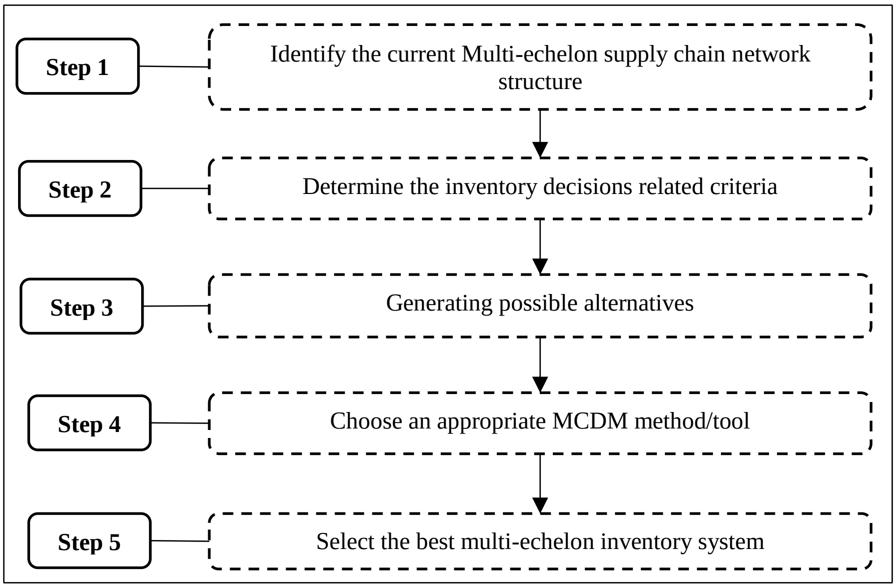

Figure 2. The proposed MCDM based framework for multi-echelon inventory system selection

As a first step, an identification of the current configuration of the supply chain network is elaborated. After that, we determine the list of criteria by considering aspects adopted in the literature that are related to inventory management. Then a list of possible alternatives is generated. We help managers choose a convenient MCDM method for their decision problem in the fifth step. Finally, the best multi-echelon inventory system given the current configuration of the supply chain network respecting the DM’s preferences is selected.

3.2 Step 1: Identification of the current multi-level supply chain network structure

In a previous work (Sbai and Berrado, 2019), we gave insights about the important elements to consider while characterizing the current supply chain network. The structure of the multi-echelon supply chain needs to be classified (for this case, it is a distribution system). Besides, the number of echelons and installations in each stage is determined in this step. Furthermore, as the inventory level in different facilities of the supply chain affects the demand function (Pervin et al., 2020), the demand nature should be defined (stochastic or deterministic, static or non-static demand). The number of product types stored in different facilities is mentioned as well.

3.3 Step 2: Presenting the selection criteria

It is assumed that inventory plays an important role in supply chain performance. In fact, at the upstream echelons of a multi-level system, the inventory can be carried as large lots to satisfy future sales or to benefit from aggregation. Moreover, at the downstream level of a multi-stage supply chain, retailers can stock up more items to ensure product availability when customers arrive (Chopra and Meindl, 2012). As a result, inventory impacts the costs incurred in the whole system and the responsiveness of the supply chain as well.

Chopra and Meindl (2012) cited the level of product availability and the amount of cycle and safety inventory as major components of inventory decisions that should be considered by managers to improve the responsiveness and the efficiency of their supply chain networks. The authors listed also important inventory metrics that shape the overall performance of the supply chain. In general, managers need to keep track of the amount of average inventory carried the number of products with a high level of inventory, the size of replenishment orders, the safety inventory in different facilities, the product availability, and the obsolete inventory.

It is well known that the overall trade-off faced by decision-makers is to have a responsive and efficient supply chain at the same time. Increasing the inventory level improves the responsiveness of the system as a whole but unfortunately amplifies the holding costs as well.

Based on the above, we selected the criteria presented in Table 2. Those criteria are going to be adopted for evaluating the alternatives.

Table 2. Multi-echelon inventory system selection related criteria

Responsiveness related criteria	**Costs related criteria**
Product availability(C3)	Handling costs (C1)
Customer service level (CSL) (C4)	Information system costs (C2)

The proposed selection criteria illustrate the main inventory-related decisions that affect the overall inventory costs and the satisfaction of the final customer. In particular, the holding costs illustrate the amount of cycle and safety inventory carried in the different facilities of the supply chain. Besides, inventory status data processing and its exchange between different installations generate information system costs and this could represent a considerable issue while choosing a multi-echelon inventory system. Furthermore, the product availability illustrates the availability of products in different facilities of the network. Finally, to measure the final customer satisfaction and the fulfilment of the orders on time, the customer service level (CSL) is chosen as a responsiveness-related criterion.

3.4 Step 3: Generating alternatives

To select the appropriate multi-echelon inventory system that matches up with the current structure of the multi-level supply chain and fulfils the decision maker's needs, a set of possible alternatives is formulated considering the inventory policies mentioned in section 2.

The process of generating multi-echelon inventory system alternatives is presented in Figure 3.

Figure 3. Process for generating alternatives for multi-echelon inventory system selection

As a first step of the process, we determine key inventory policies used in connection to multi-echelon inventory systems. After that, we determine the decision nodes/variables. To explain, the choice/determination of any of the inventory policies is conditioned by deciding some important aspects related to the current configuration of the supply chain in question. Before choosing a replenishment policy, we need to know if there is an information system that can track continuously the inventory status in all sites of the supply chain. More than that, the information about the orders management is also important. We need to know if the current system is managing replenishments centrally or in a decentralized manner. We will discuss some other decision nodes later in this section. Finally, the third step concerns generating alternatives.

As mentioned earlier, we consider the distribution inventory system structure in this paper. We develop the alternatives formulation process for distribution inventory systems in section 4.

After characterizing the current structure of the supply chain, listing the selection criteria based on the inventory-related decisions, and building the set of possible multi-echelon inventory system alternatives, the choice of an MCDM method is investigated in the next step.

3.5 Step 4: Choice of an MCDM Method

The choice of the suitable MCDM method for the multi-echelon inventory system selection presents an important step in our proposed framework. There are numerous MCDM methods developed by the literature, and which have been applied to the supply management research area. However, not all MCDM methods can give the best solution to a given decision problem (Wątróbski et al., 2019). For this purpose, we developed in a previous work (Sbai et al., 2020) an MCDM method selection approach for choosing the appropriate decision-making methodology for the multi-echelon inventory system selection problem. The suggested approach involved the following steps: (i) Determining the main characteristics of the multi-echelon inventory system selection problem, (ii) Defining key properties and abilities of different MCDM methods, (iii) Building a set of selection criteria, (iv) Comparing MCDM methods according to the selection criteria and finally (v) Selecting and choosing the appropriate MCDM method.

The MCDM method selection-related criteria involved both the decision–making problem properties and general criteria proposed by the literature that should be fulfilled by the MCDM method that will be applied to the problem situation. We chose the type of alternatives, the relative importance of attributes, the ease of use of the methodology, and the comparison scale of the options as selection criteria for choosing the MCDM method that corresponds the most to the multi-echelon inventory system selection problem.

3.6 Step 5: Selecting the multi-echelon inventory system

The last step of our framework is selecting the appropriate multi-echelon inventory system for the given supply chain structure. By applying a suitable MCDM method to the present decision problem, the evaluation of possible alternatives results in selecting the appropriate multi-echelon inventory system. We illustrate our suggested framework in section 5.

4. Generating alternatives for multi-echelon inventory system selection problem: Case of distribution systems

The allocation of the total inventory in a distribution system may depend on several factors such as demand variations, units costs, or transportation time. Carrying large inventory in an upstream facility (warehouse) or downstream installations (retailers) always represents a trade-off. We described in section 2 the inventory policies used in connection with multi-echelon inventory systems in general. In this part, we will specify the most used inventory policies in multi-echelon distribution inventory systems as well as key decision nodes related to the nature of this structure.

- **Defining inventory policies**
  - Replenishment policy: continuous or review policy
  - Ordering policies: installation stock ordering policy or echelon stock ordering policy
  - Safety stock policies: allocating safety stock in upstream installations or downstream installations
  - Lot sizing: It is very common in the literature to use the “Roundy’s approximation” method in distribution systems (Axsäter, 2015).
- **Determining decision nodes**

Besides what was mentioned earlier in this section, the choice of the safety stock policy is related to the value of the products and the transportation time. In the case of distribution systems, information about the reorder interval of the suppliers/ retailers is required also (Chopra and Meindl, 2012).

In short, we can derive from the literature five decision nodes for generating multi-echelon distribution inventory system alternatives:

- The ownership of an information system that manages the inventory status in the different facilities.
- Reorder interval of the supplier/ retailer.
- Type of the decision system: centralized or decentralized. A centralized decision system allows for having and exchanging information about inventory status at all sites continuously or periodically (Karaarslan, 2012). This information is used to replenish products centrally (federgruen 1993). In a decentralized decision system, the different facilities replenish separately in a decentralized manner.
- Product holding costs and transportation time are tolerated by the final customer.

- **Generating alternatives**

To formulate possible alternatives, we followed the process illustrated in Figure 4. While choosing a replenishment policy, we need to know if the current supply chain has already an information system that connects all the inventory status data at all sites. This will create an opportunity for the manager to adopt a continuous review policy. Then, the reorder interval of the retailers is determined with a correlation to the suppliers' reorder interval. If the retailers have longer reorder intervals than their supplier, the supplier’s reorder interval is fixed as an integer multiple of the customer’s interval. After that, the decision system settled should be specified. A centralized decision system will make it easier for an echelon stock ordering policy to be implemented. At last, the allocation of safety stocks depends on the holding costs of the products as well as the transportation time to send the delivery to the final customer.

Considering the above, the inventory policies presented in the first step of the process illustrated in Figure 3, a review of existing models elaborated in a previous research paper , and the work (Axsäter, 2015), we built the multi-echelon distribution inventory system alternatives listed in Table 3.

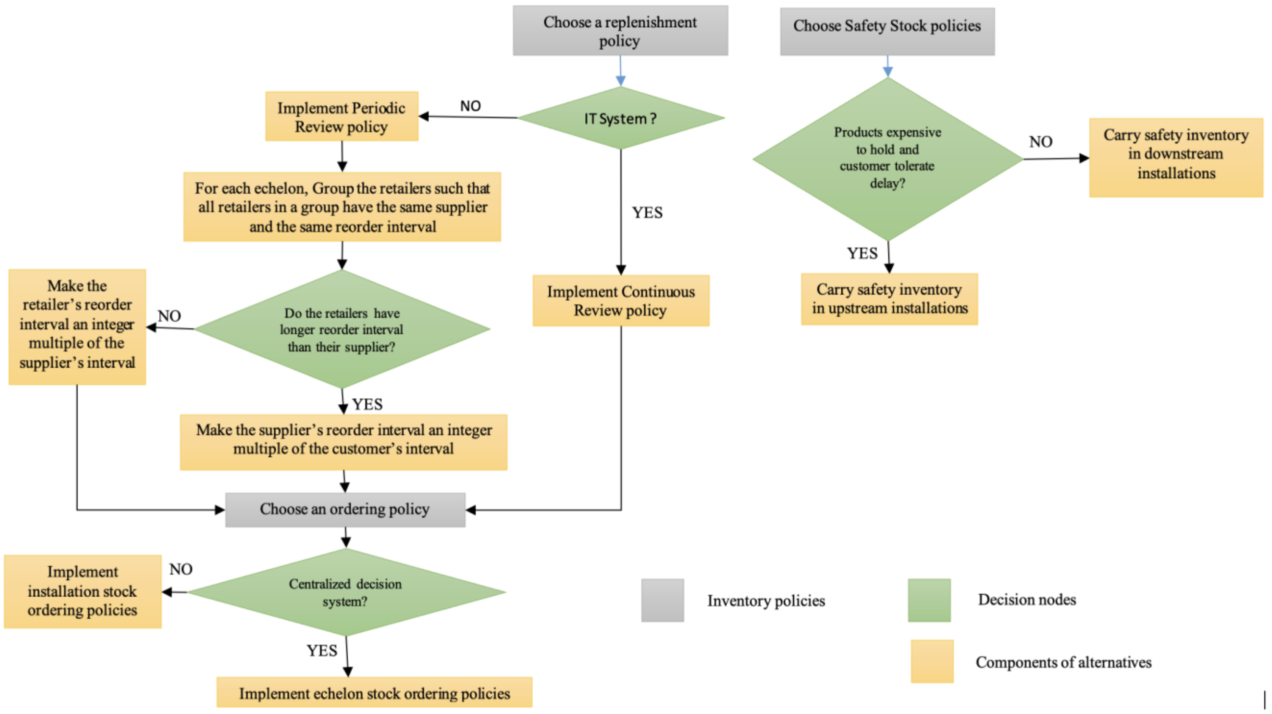

Figure 4. Process of generating alternatives for multi-echelon inventory system selection: the case of distribution systems

Table 3. Alternatives for multi-echelon inventory system selection: the case of distribution systems

Alternative	Replenishment policy	Ordering policy	Safety stock policy	Description
AD1	Continuous review policy	Echelon stock ordering policy	Carry safety inventory upstream	The current supply chain owns an information system that provides data about inventory status at all facilities which allow using a continuous inventory policy. The information system settled implements echelon stock ordering policies possible as well. The safety inventory is stored in the upstream stages.
AD2	Continuous review policy	Echelon stock ordering policy	Carry safety inventory downstream	In this option, the decision-maker can adopt the same replenishment policy and ordering policy mentioned in AD1 and chooses to carry safety inventory in downstream installations.
AD3	Continuous review policy	Installation stock ordering policy	Carry safety inventory upstream	While the decision system is decentralized, it is convenient that each site makes its orders separately. A continuous review policy is adopted in this case. The allocation of safety inventory is kept in upstream installations.

Table 3. Continued

Alternative	Replenishment policy	Ordering policy	Safety stock policy	Description
AD4	Continuous review policy	Installation stock ordering policy	Carry safety inventory downstream	The replenishment policy and ordering policy are the same as AD3. The safety inventory is stored at the downstream level.
AD5	Periodic review policy	Echelon stock policy	Carry safety inventory upstream	An information system is not available in the current supply chain so a periodic review policy is recommended. The ordered quantities are decided centrally which enables the use of echelon stock ordering policies. The safety inventory is allocated upstream.
AD6	Periodic review policy	Echelon stock policy	Carry safety inventory downstream	The replenishment policy, as well as the ordering policy, are the same as AD5. The safety inventory is carried downstream in this case.
AD7	Periodic review policy	Installation stock policy	Carry safety inventory upstream	The inventory is checked periodically after a review period. The quantities are ordered in a decentralized manner. Thus an installation stock ordering policy is recommended. In this option, the safety inventory is carried in upstream facilities.
AD8	Periodic review policy	Installation stock policy	Carry safety inventory downstream	The replenishment policy and the ordering policy are identical to those in AD7. The safety inventory is allocated to the lower level of the supply chain.

5. Application of MCDM based approach for multi-echelon inventory system selection: Case of pharmaceutical products supply chain in Moroccan Public Sector

The aim of Supply Chain in Healthcare is to identify departmental problems and recommend solutions to mitigate them. Its goal is to recognize vulnerable areas so that targeted health outcomes can be achieved, as well as to increase global health investment. Improved operations, efficient resource use, motivated personnel, timely treatment, and happy patients are all benefits of an efficient supply chain in healthcare (Arora and Gigras, 2018). In this context, inventory management is one of the most fundamental tasks in the pharmaceutical supply chain; it necessitates major investments and careful management because it is related to human life (Mouaky et al., 2019).

The management of the Moroccan Pharmaceutical products supply chain has known major changes in recent decades. The Ministry of Health has become very concerned about the importance of supply chain management to improve the accessibility of patients to health care and medicines.

The actual supply chain faces various issues related to product stock-outs, inventory obsolescence due to the expiration of pharmaceuticals before use, and low product availability in some healthcare centres.

To help the supply chain division address those problems, we apply the proposed approach for multi-echelon inventory system selection to the case of the Moroccan pharmaceutical supply chain. In this section, we present the application of the steps of our methodology, and we discuss the results.

5.1 Step 1: The current Moroccan pharmaceutical products supply chain structure

The Moroccan Pharmaceutical products supply chain is characterized by a common strategic vision. The customers of the Supply Division, namely the regional and provincial/prefectural hospitals and the delegations, express their needs in medicines and health products according to a standardized order form and a framework specifying the strategic orientations of the Ministry of health for the prioritization of certain pathologies. Besides, the supply division/department aggregates the annual orders of its customers and draws up a supply program forecast. The delivery schedule is communicated to the suppliers after the approval of the Contracts. Distribution planning is done by considering customer orders received and following an internal schedule within the supply division. After that, a notice is sent to customers informing them of the date of delivery and the products to be delivered.

A collaborative approach in the execution of the supply chain processes was adopted by the pharmaceutical supply chain of Morocco. The supply chain department in the ministry of health is governed by a committee including central directors, regional directors, and other divisions' chiefs. This committee was created to optimize governance and coordination between the various stakeholders in the process of acquiring and distributing pharmaceuticals and health products.

Sharing performance indicators is between the main objectives of the Ministry of Health in Morocco. Performance indicators for the activity of the Supply Division have been put in place for full information sharing. The supply chain department in collaboration with the Information Technology (IT) department, and the Hospital division and ambulatory care, is in the process of implementing a system of interfaced information for the management of the various processes in the supply chain and at all levels of the health sector. The supply chain department will thus gain maturity and integration. The current supply chain is organized around 40 laboratories, 1 central warehouse, and 3 other secondary warehouses, 8 regional pharmacies, 88 provincial pharmacies, 150 hospital pharmacies, and more than 2750 basic healthcare facilities and health centers widely spread throughout the country to provide all citizens access to healthcare. We illustrate in Figure 5 the current network of the Moroccan pharmaceutical products supply chain (TADLAOUI et al., 2015).

As we can see in Figure 5, The Moroccan pharmaceutical products supply chain is a multi-echelon distribution system. It is composed of four echelons. (i) Echelon 1: Central warehouse and 3 other secondary warehouses, (ii) Echelon 2: Four regional warehouses, (iii) Echelon 3: Regional pharmacies, provincial pharmacies, and hospital pharmacies, and finally (iv) Echelon 4: basic health care facilities. We provide in Table 4 different activities performed by warehouses.

Besides that, and during this phase of our proposed approach, we need to determine different demand characteristics. In the Moroccan pharmaceutical products supply chain, necessary data/information to quantify the needs for pharmaceutical inputs are not always reliable. Besides, for a given year "N", the estimation of needs in pharmaceutical inputs and their purchases are made for the year "N + 1" and not for the current year "N". More than that, there is the matter of unreliability of epidemiological data. This is related to forecasts of relevant products coming from public health programs. Finally, there is no integrated supply chain management information system in place. Another important element to be determined at this stage is information regarding lead time and issues related to it. Respect for deadlines and the work of technical commissions cannot be controlled. Another problem faced by this supply chain in terms of lead time is the expensive price for certain items. Finally, the delay in the delegation of credits results in delays in approving contracts and therefore delay in deliveries.

5.2 Step 2: Presenting the selection criteria

The main objective of our multi-echelon inventory system selection approach is to help decision-makers choose the appropriate inventory policies for their systems. Besides that, we aim to strengthen the responsiveness of the Moroccan pharmaceutical supply chain to guarantee accessibility and availability of pharmaceuticals to improve service quality for final customers /patients. We are going to adopt the set of criteria presented in Table 2 in the previous section.

Table 4. Activities performed by Moroccan pharmaceutical products supply chain warehouses (Ministère de la santé, 2018).

Facility/Installation	Activities allocated
Central warehouse	- Storing pharmaceutical products - Reception, storage, and dispatch of urgent orders for pharmaceutical products to health care centres and hospitals of the Ministry of Health. - Inventory management - Planning for deliveries with the Supply Division and the transport subcontractor - Monitoring of supply in collaboration with the department concerned. - Coverage of the entire national territory
Secondary warehouses	- Storing contraceptives. - Reception, storage, and dispatch of urgent orders for pharmaceutical products to health care centres and hospitals of the Ministry of Health. - Inventory management - Planning of deliveries with the Supply Division and the subcontractor - Reacting and medical logistic - Monitoring of Supply in collaboration with the service concerned - Coverage of the entire national territory. - Reception, storage, and dispatch of urgent orders for massive solutes and biomedical equipment to delegations and Hospitals of the Ministry of Health. - Storing pharmaceutical products: haemodialysis, dental and cataract kits.

5.3 Step 3: Generating possible alternatives

As it was mentioned in the first step of our approach, the Moroccan pharmaceutical supply chain is a multi-echelon distribution system. For that, we are going to adopt the set of alternatives that we presented in Table 3. Eight multi-echelon inventory system alternatives were suggested. Each option is a combination of three main elements: replenishment policy, ordering policy, and safety stock allocation policy. We adapted the alternatives defined in Table 3 to the Moroccan pharmaceutical supply chain structure described in the first step. The alternatives are represented and described in Table 5.

5.4 Step 4: Choice of an MCDM method

We elaborated in previous work (Sbai et al., 2020) a comparison of MCDM methods for multi-echelon inventory system selection problem. This research paper aimed to help Decision Makers (DMs) select an appropriate MCDM method for choosing the multi-echelon inventory system that corresponds to their preferences. We provided an approach for comparing multiple MCDM methods for the multi-echelon inventory system selection problem.

The proposed approach is composed of the following steps: (i) Identification and characterization of the multi-echelon inventory system selection problem, (ii) Determination of key abilities of different MCDM tools, (iii) Selection criteria definition, (iv) Comparison of MCDM methods using the selection criteria and finally (v) selection of the suitable MCDM method for multi-echelon inventory system selection problem.

Taking into account the previous decision problem characteristics and the preferences of our DMs, and using the approach developed in previous work (Sbai et al., 2020), we conclude that AHP fulfils the requirements and appears to be the suitable MCDM method to apply for the Moroccan pharmaceutical products multi-echelon inventory system selection problem.

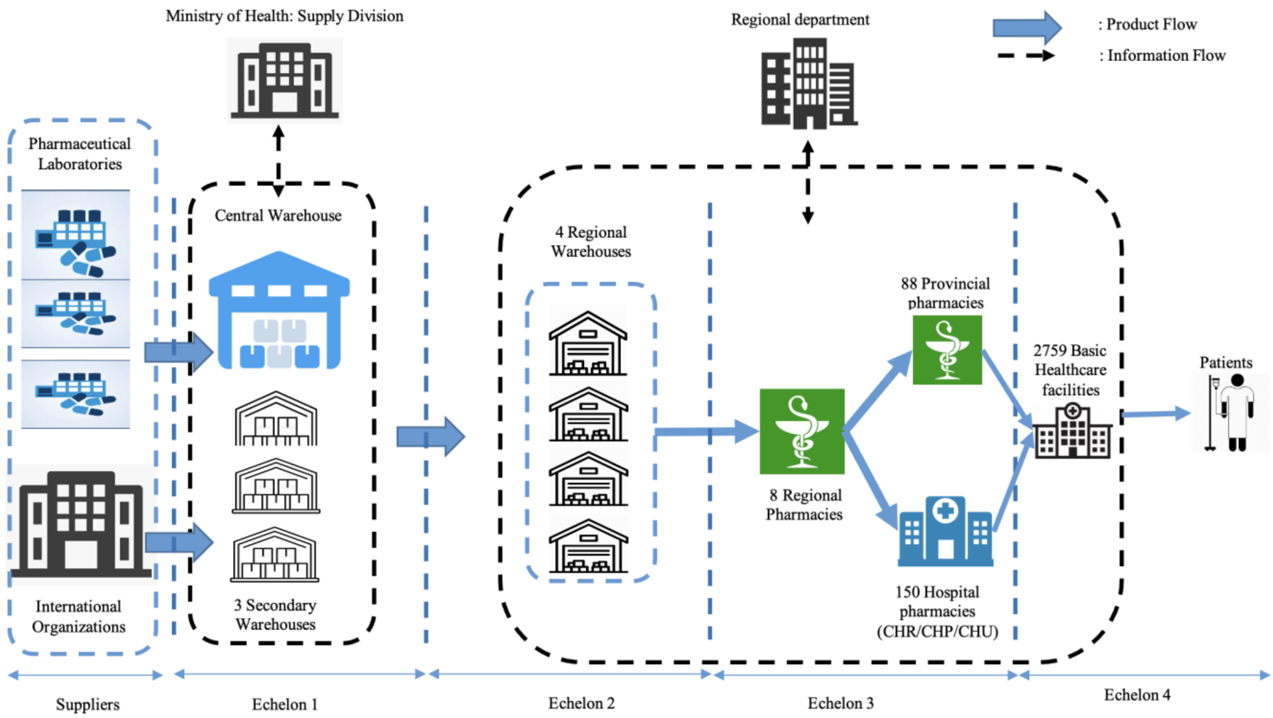

Figure 5. Current Structure of the Moroccan multi-echelon pharmaceutical supply chain in the public sector

5.2 Selecting the best multi-echelon inventory system for Moroccan pharmaceutical products supply chain

5.2.1 AHP hierarchical model

As stated in previous steps, AHP was used in this work to compare and evaluate different multi-echelon inventory system alternatives. AHP is an MCDM tool for ranking alternatives. It employs pairwise comparisons and is associated with a consistency ratio (Asadabadi et al., 2019). The AHP allows for inconsistencies in judgments while also offering a way to increase consistency (Saaty and Vargas, 2012). Saaty and Ergu (2015) stated that AHP seems to be the only theory that comes near to the understanding, and its mathematics easily generalizes to interdependence and feedback. Besides, the authors mentioned that AHP employs absolute priority scales that can be linked to generate absolute numbers.The most significant benefit of AHP is the hierarchy structure of the model it considers, and thus, the element of hierarchy in the AHP method can relate to any application of decision-making problem that requires an individual to choose among potential alternatives and search for the weight of evaluation index (Yazdani, 2014). As a first step of applying AHP, our decision problem is structured or decomposed into a hierarchy (Figure 7). On the first level is the overall goal of choosing the appropriate multi-echelon inventory system for the Moroccan pharmaceutical supply chain. On the second level are the four criteria that contribute to the goal, and on the third level are the eight alternatives that are to be assessed in terms of the selected criteria on the second level.

Table 5. Alternative multi-echelon inventory systems for the pharmaceutical supply chain

Alternative	Description

AD1	The Moroccan supply chain needs to purchase/ own an information system for supply chain management that provides data about inventory status at all facilities to be able to adopt a continuous inventory policy. If the management decides to have a centralized decision system, product quantities are determined by the supply division of the ministry of health. More than that, an echelon stock ordering policy can be implemented. Thus, all facilities are going to adopt echelon stock inventory positions for determining to reorder points. In this alternative, the pharmaceutical products' safety inventory is stored in the central warehouse and the three secondary warehouses.
AD2	In this option, the decision-maker may adopt the same replenishment policy and ordering policy as AD1. The only difference is that pharmaceutical product safety inventory will be allocated close to patients in hospital pharmacies and basic healthcare systems.
AD3	In this option, the Moroccan pharmaceutical supply chain adopts a continuous inventory policy. If a centralization of inventory management is not possible, a decentralized decision system is adopted, and the quantities of the products are decided by regional departments. Consequently, an installation stock ordering policy is implemented, and each facility determines the ordering quantities based on its inventory position. The pharmaceutical products' safety inventory is carried in the central warehouse and the three secondary warehouses.
AD4	The replenishment policy and ordering policy are the same as AD3. The pharmaceutical products' safety inventory is stored near to patients in hospital pharmacies and basic healthcare facilities.
AD5	The Moroccan pharmaceutical supply chain doesn't purchase an information system dedicated to supply chain management. In that case, a periodic review policy is adopted. This means that pharmaceuticals are ordered after fixed periods and regularly. The supply chain uses a centralized inventory control system and so all facilities use an echelon inventory position for reorder points. In this option, the pharmaceutical products safety inventory is carried in the central warehouse and the three secondary warehouses.
AD6	The replenishment policy, as well as the ordering policy, are the same as AD5. The safety inventory is allocated to hospital pharmacies and basic healthcare facilities.
AD7	Inventory control is decentralized. Each inventory facility makes its orders based on the installation inventory position only. The products are ordered periodically after a fixed period. The safety inventory for different pharmaceuticals is stored in the central warehouse and the secondary warehouses.
AD8	The replenishment policy and the ordering policy are identical to those of AD7. The only difference is the choice to allocate the safety inventory of pharmaceuticals to hospital pharmacies and basic healthcare facilities.

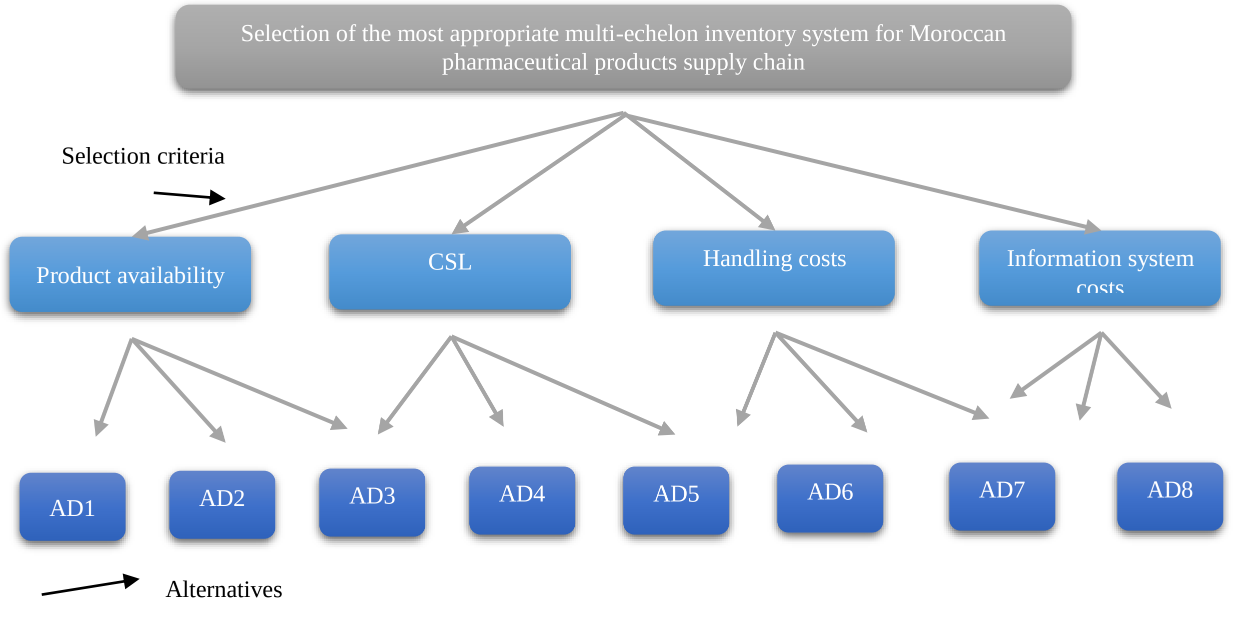

Figure 5. AHP hierarchical model of the Moroccan pharmaceutical products supply chain

5.2.2 Determination of multi-echelon inventory system alternatives weights across criteria

A definite number within a scale from 1 to 9 is assigned for calculating priority vectors when making comparisons. The AHP scale of relative importance used for pairwise comparisons is given in Table 6. We give examples of pairwise comparison of multi-echelon inventory system alternatives against CSL and handling costs in Tables 7 and 8. Pairwise comparison tables are constructed based on performance evaluation of alternatives according to the selected criteria and the Ministry of Health experts' judgment. Particularly, the multi-echelon inventory system AD6 is "strongly more important" than AD7 when it comes to product availability since safety inventory is allocated in downstream facilities (hospital pharmacies and basic healthcare facilities). Besides, AD5 has a demonstrated importance over AD8 when it comes to handling costs since a centralized policy is adopted and safety inventory is allocated to upstream stages (the central warehouse and the three secondary warehouses). Aggregated multi-echelon inventory system alternatives weights are presented in Table 9. We provide a graphical illustration of the priority vectors in Figure 7.

5.2.3 Criteria weights

To determine the relative importance of criteria, several discussions were conducted with the Ministry of Health. The decision-makers consider product availability and Customer Service as criteria with high priority. We present in Table 10 the pairwise comparison of criteria and we illustrate in Figure 8 their aggregated weights. We can observe that Customer Service Level has about 56, 93% importance, followed by product availability with 32,87%. Handling costs and Information Systems costs with 3, 40%, and 6, 80% respectively have the lowest importance. The weights reflect that supply chain responsiveness-related criteria are significantly important for the Ministry of Health decision-makers.

Table 6. Pairwise comparison scale (Saaty and Vargas, 2012)

Intensity of importance	**Description**
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

Table 7. Multi-echelon inventory systems pairwise comparison for handling costs

Handling costs	**AD1**	**AD2**	**AD3**	**AD4**	**AD5**	**AD6**	**AD7**	**AD8**	**Priority vectors**	**weights**
AD1	1	3	3	6	3	5	7	7	3,76	0,325
AD2	1/3	1	1	5	1	4	5	7	1,98	0,171
AD3	1/3	1	1	5	1	4	5	7	1,98	0,171
AD4	1/6	1/5	1/5	1	1/5	1/3	1	3	0,44	0,038
AD5	1/3	1	1	5	1	4	5	7	1,98	0,171
AD6	1/5	1/4	1/4	3	1/4	1	3	4	0,76	0,066
AD7	1/7	1/5	1/5	1	1/5	1/3	1	3	0,43	0,037
AD8	1/7	1/7	1/7	1/3	1/7	1/4	1/3	1	0,24	0,021
Total	2,65	6,79	6,79	26,33	6,79	18,92	27,33	39,00	11,56	1,00

CI= 0,060

CR= 0,043<0,1

Table 8. Multi-echelon inventory systems pairwise comparison for product availability

Product-Availability	**AD1**	**AD2**	**AD3**	**AD4**	**AD5**	**AD6**	**AD7**	**AD8**	**Priority vectors**	**weights**
AD1	1	1/4	3	1/4	3	1/4	4	1/3	0,81	0,07
AD2	4	1	5	1	5	1	7	3	2,60	0,23
AD3	1/3	1/5	1	1/5	1	1/5	3	1/4	0,46	0,04
AD4	4	1	5	1	5	1	7	3	2,60	0,23
AD5	1/3	1/5	1	1/5	1	1/5	3	1/4	0,46	0,04
AD6	4	1	5	1	5	1	7	3	2,60	0,23
AD7	1/4	1/7	1/3	1/7	1/3	1/7	1	1/5	0,25	0,02
AD8	3	1/3	4	1/3	4	1/3	5	1	1,31	0,12

Total	16,92	4,13	24,33	4,13	24,33	4,13	37,00	11,03	11,10	1,00

CI= 0,043

CR= 0,030<0,1

Table 9. Multi-echelon inventory system alternatives aggregated priority weights

	Handling costs	Information systems costs	Product Availability	Customer Service Level (CSL)
AD1	0,3251	0,0287	0,0731	0,1135
AD2	0,1711	0,0287	0,2343	0,1135
AD3	0,1711	0,0581	0,0414	0,1135
AD4	0,0378	0,0581	0,2343	0,3694
AD5	0,1711	0,1143	0,0414	0,0315
AD6	0,0659	0,1143	0,2343	0,1135
AD7	0,0371	0,2989	0,0227	0,0315
AD8	0,0209	0,2989	0,1184	0,1135

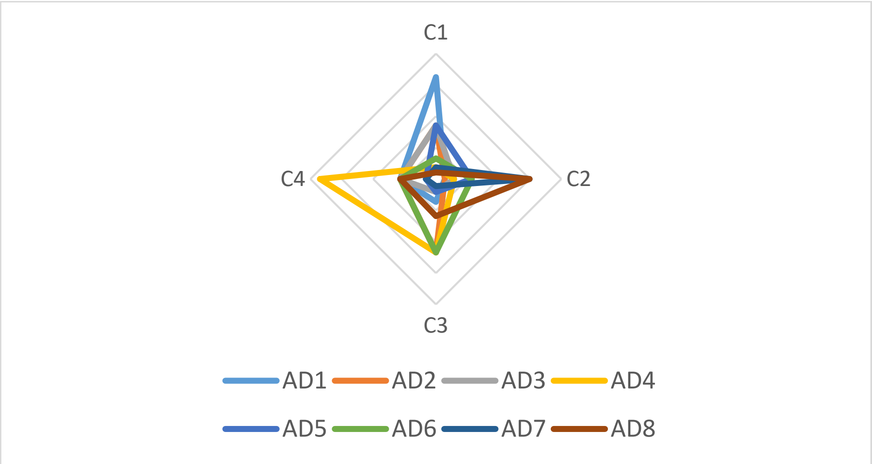

Figure 6. Multi-echelon inventory system alternatives scores across criteria

Table 10. Criteria Pairwise comparison

	Handling costs	IT costs	Product Availability	CSL	Priority vectors	weights
Handling costs	1	1/4	1/9	1/9	0,24	0,03
IT costs	4	1	1/9	1/9	0,47	0,07
Product Availability	9	9	1	1/3	2,28	0,33
CSL	9	9	3	1	3,95	0,57
Total	23,00	19,25	4,22	1,56	6,93	1,00

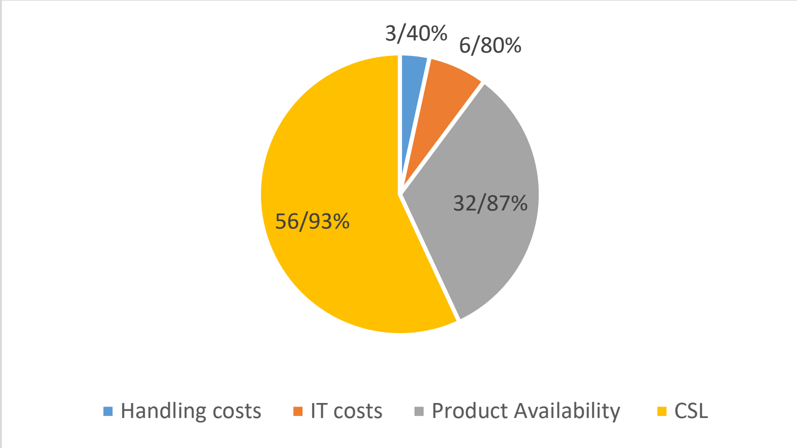

Figure 7. Criteria Weights

5.2.4 Resulting multi-echelon inventory system alternatives' ranking and discussion

One of the AHP's major advantages is that it considers decision-makers' inconsistencies. The consistency Relationship value is obtained as CR=CI/RI, where CI is the Consistency Index and RI is the Random Consistency Index (Saaty, 2008). CI is a measure of the inconsistency index of a matrix of comparisons. Details of the CI calculations can be found in (Saaty and Vargas, 2012).

The consistency ratio (CR) is calculated by comparing the CI to one of the numbers in Table 11, each of which represents an average random consistency index determined from a sample of randomly generated reciprocal matrices using the fundamental scale shown in Table 6. If it is not less than 0.10, it is recommended to review the problem and reconsider the judgments (Saaty and Vargas, 2012).

In our case RI=1, 40 for the 8 multi-echelon inventory system alternatives matrix and RI=0,89 for the 4 criteria matrix. Different values of CR were less than 0.1 which reflects acceptable judgments.

Table 11. Scales of Random Consistency Index (RI) (Saaty and Vargas, 2012)

N*	1	2	3	4	5	6	7	8	9	10
Random consistency Index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

In this final step of the approach, we determine the multi-echelon inventory system alternatives' ranking to select the best one. We illustrate in Table 12 the ranking of alternatives according to AHP. The alternative AD4 which combines a continuous review policy, installation stock ordering policy where each facility makes orders based on its inventory position, and safety inventory allocated in hospitals and basic healthcare facilities close to patients, is the most appropriate multi-echelon inventory system option for the Moroccan Ministry of Health.

The results obtained by the application of the approach to the case of the Moroccan Pharmaceutical supply chain show that supply chain responsiveness can be achieved but with significant costs and by allocating inventory to most downstream facilities close to patients. Besides, the installation stock ordering policy performed under a decentralized decision system seems to be the most appropriate for our case. The Ministry of Health preferences were clearly stated as giving high priority to product availability and customer service and this was confirmed by the results obtained. More efforts are going to be put to guarantee a high level of patient satisfaction.

The results obtained by the application of our proposed approach depend significantly on the structure of the current multi-echelon inventory system. In other words, the number of echelons, facilities, demand type, lead time, and other elements set a basis for applying the suggested approach and this requires a careful determination and characterization of those factors. Our approach suggests evaluating several multi-echelon inventory system alternatives according to a set of selected criteria. These criteria reflect the decision maker's preferences. Inventory-related decision metrics that reflect the supply chain responsiveness and efficiency were selected as the main factors to be considered in the alternatives assessment. The application of AHP as the most appropriate MCDM method for our decision problem was very helpful in terms of efficacy and ease of use.

* N represents the matrix size.

Table 12. Ranking of multi-echelon distribution inventory systems according to AHP: Case of pharmaceutical products supply chain in Moroccan Public Sector

Alternatives	Final Score
AD4	0.2926
AD6	0.1517
AD2	0.1494
AD8	0.1246
AD1	0.1017
AD3	0.0880
AD7	0.0470
AD5	0.0451

6. Conclusion

In this paper, we proposed an MCDM based approach for multi-echelon inventory system selection. We focused especially on the case of distribution systems. The first step of the suggested approach is to characterize the current supply chain network. The next step consists of determining the criteria for selection and that by considering the decision maker's preferences as well. After that, we built alternatives for each distribution inventory system structure by taking into consideration major inventory policies such as replenishment policies, ordering policies, and safety stock allocation policies. Eight multi-echelon inventory system alternatives were suggested. Then, we choose the MCDM method that corresponds to the decision problem characteristics. Finally, we apply the MCDM tool to select the best multi-echelon inventory system alternative.

We applied the proposed approach to the case of the pharmaceutical products supply chain in the Moroccan public sector. The ranking of multi-echelon distribution inventory systems selection problem is formulated as a ranking problem using AHP, which is an effective and easy-to-use method for ranking alternatives. The results showed that allocating inventory to most downstream facilities close to patients and using an installation stock ordering policy performed under a decentralized decision system is the most appropriate alternative for our case. The Ministry of Health preferences were clearly stated as giving high priority to product availability and customer service and this was confirmed by the results obtained.

Finally, the formulation of multiple alternatives for multi-echelon distribution inventory systems presented in this paper will aid in the development of an approach for simulating and comparing various multi-echelon inventory system alternatives to assist decision-makers in selecting and validating the appropriate multi-echelon inventory policies that match their preferences and correspond to their supply chain networks. This could be considered for future work.

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