Redesigning a transportation network: the case of a pharmaceutical supply chain

Afaf Haiial*

Equipe MOAD-SCM, EMI,
Mohammed V University,
Rabat, Morocco
Email: afafhaiial@gmail.com
*Corresponding author

Abdelaziz Berrado

Equipe AMIPS, EMI,
Mohammed V University,
Rabat, Morocco
Email: berrado@emi.ac.ma

Loubna Benabbou

Equipe MOAD-SCM, EMI,
Mohammed V University,
Rabat, Morocco
Email: benabbou@emi.ac.ma

Abstract: Designing transportation networks – as one of the most important decision problems in supply chain management – has become the focus of research attention in recent years. This paper introduces a framework which deals with the design of a transportation network for pharmaceutical supply chains. It consists of three steps: 1) identifying the configuration of the current distribution network; 2) designing an optimal distribution network while determining the appropriate location-allocation decisions; 3) choosing the most appropriate transportation network through the application of the appropriate multi-criteria decision analysis method (MCDA). The proposed framework is illustrated in redesigning a transportation network for a pharmaceutical supply chain.

Keywords: pharmaceutical products supply chain; supply chain transportation network; location-allocation; multi-criteria decision analysis.

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Biographical notes: Afaf Haiial is a PhD student in Modeling and Decision Support – Supply Chain Management Research Structure at the Ecole Mohammadia d'Ingénieurs (EMI) at Mohamed V University. She received her

degree in Industrial Engineering from the Ecole Nationale Supérieure des Mines de RABAT (ENSMR) in 2013. Her main research interests are supply chain management, and transport policy with a special focus on pharmaceutical products.

Abdelaziz Berrado PhD is the Department Chair and Associate Professor of Industrial Engineering in EMI School of Engineering at Mohamed V University in Rabat. He holds a PhD degree in Decision Systems and Industrial Engineering from ASU. His research, teaching and consulting interests are in the areas of big data analytics, industrial statistics, operations and supply chain modelling, planning and control with applications in healthcare, education and other industries. He published several papers in research journals and conferences with local and international funding. He is member of INFORMS, IEOM and IEEE. He was also a Senior Engineer at Intel.

Loubna Benabbou is an Associate Professor of Industrial Engineering at Ecole Mohammadia d'Ingénieurs (EMI) at Mohamed V University. Her research works lie in the application of decision/management sciences and machine learning techniques. Several of her research paper has been published in international scientific journals and conferences' proceedings. She was also a trader at Casablanca stock-exchange and financial analyst and risk manager at the Caisse Marocaine des retraites. She is member of INFORMS, IEEE and International Society of MCDM. He is an Industrial Engineer from EMI. She earned her MBA and PhD in Management and Decision Sciences from Laval University.

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1 Introduction

Supply chain is considered as an integrated process in which a group of organisations such as manufacturers, suppliers, transporters, distributers and retailers work together to fulfil a customer request (Chopra and Meindl, 2003). Supply chain management is the process of planning, controlling and implementing the overall functions of the supply chain in order to meet customer requirements as efficiently and effectively as possible (Chopra and Meindl, 2003; Sezhiyan et al., 2011; Göpfert and Wellbrock, 2013). Among the large amount of published research work on supply chain management, only few of these studies deal with the pharmaceutical sector.

The global pharmaceutical industry has seen rapid growth over the past few years and considered as one of the fastest-growing industries in the world (Lorenzetti, 2015). However, large parts of the world's population die every year, mostly in low income developing countries, due, in part, to the unavailability of essential drugs (World Health Organization and United Nations Children's Fund, 2009).

In developing countries, like Morocco, access to essential pharmaceutical products remains a real problem due to challenges faced by its pharmaceuticals supply chain, such as inadequate design of the supply chain, poor physical infrastructure and lack of appropriate supply chain planning approaches (Ecumenical Pharmaceutical Network, 2011). Therefore, the developing countries should work on establishing an effective and efficient pharmaceutical supply chain, to ensure that their population will have access to essential pharmaceutical products at the right place and at the right time (Enyinda et al., 2010).

Successful supply chain management requires many decisions relating to the different flows of goods between suppliers and customers, which are broadly classified under (Chopra and Meindl, 2003):

- Supply chain strategic decisions: they are typically made for the long term (a matter of years) and are very expensive to alter on short notice; they are associated with the supply chain's structure over the next several years.
- Supply chain planning decisions: they cover a period of a few months to a year, these decisions are about the establishment of the different parameters within which a supply chain will operate for a particular period of time.
- Supply chain operational decisions: they are made in the short time (weekly or daily), this phase concerns the decision-making regarding individual customer orders.

Supply chain's transportation network design is one of the most important strategic decisions that affect the whole supply chain (Chopra and Meindl, 2003). Thus, the choice of the appropriate transportation network is one of the most important design tasks that supply chain managers should focus on.

Furthermore, the supply chain's transportation network decisions are inextricably linked to the design of their distribution network (Burke, 2005). A well-designed transportation network ensures that the products with the right quality and right quantity are delivered to customers at the right time, right place and right cost. In this paper, we are interested in presenting a framework for designing a transportation network in a pharmaceutical supply chain.

The rest of the paper is organised as follows: we provide a presentation of the problem at hand in Section 2. Section 3 consists of a literature review. The suggested framework is presented in Section 4. Section 5 provides an illustration of our framework in redesigning a transportation network for the Moroccan pharmaceutical supply chain. Finally, conclusion and future research follow.

2 Problem definition

Structuring supply chain networks is a complex decision-making process (Melo et al., 2009). The typical goal of this process is producing and delivering the products of right quality and right quantity, at right time, right place and right cost to all customers (Manimaran et al., 2011). In order to reach the supply chain process's goal, different decisions including facility location, production, inventory and transportation should be made so as to meet customer demands in the most effective and efficient way.

Transportation plays a central role in seamless supply chain operations (Stank and Goldsby, 2010). By moving inbound goods from supply sites to manufacturing facilities, repositioning inventory among different warehouses and distribution centres, and delivering finished products to customers, transportation provides the essential service of linking the whole supply chain from suppliers to customers (Jacyna, 2013).

As one of the major supply chain drivers, transportation has a large impact on both responsiveness and efficiency of the supply chain (Chopra and Meindl, 2003). By means of well-handled transportation network and appropriate transportation modes, products of right quality and right quantity could be sent to all customers at right time, right place and right cost (Tseng et al., 2005).

Thus, the choice of the appropriate transportation network, that improves the efficiency and responsiveness of the supply chain, is one of the most important operations that transportation managers should focus on.

A supply chain's transportation network design decision is totally linked to its distribution network design decisions (Burke, 2005). In fact, a well-designed transportation network depends on various distribution decisions, including facility location and allocation.

The decision problem considered in our research is designing a transportation network while taking into consideration the location-allocation decisions as one of the factors that influence the design of the transportation network (Bukre, 2005).

Hence, it is necessary to first determine the optimal location allocation decisions and then choose the most appropriate transportation network design option that may suit the supply chain distribution structure. In paper, we introduce a framework for designing an appropriate transportation network for a supply chain.

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3 Literature review of transportation network design

In this section, we discuss different modes of transportation and a variety of transportation network design options, then we briefly review literature devoted to the location-allocation problem.

3.1 Designing the transportation network

The design of a transportation network affects the performance of the whole supply chain by implementing the infrastructure in which several transportation decisions regarding scheduling and routing are made (Chopra and Meindl, 2003). It used to find the way of transporting products from several sources to several destinations, so that the total cost can be minimised without sacrificing customer responsiveness (Chopra and Meindl, 2003).

In the following, we discuss the role of transportation in a supply chain, including modes of transportation and different options for designing transportation networks.

3.1.1 Modes of transportation and their performance characteristics

The movement of products from a source to a destination can be undertaken using one or a combination of the following modes of transport: Air, package carriers, truck, rail, water, and pipeline (Chopra and Meindl, 2003). Every mode of transport has specific characteristics in terms of equipment investments and operating decisions by the carrier as well as the available infrastructure and transportation policies.

Air is the fastest and the most expensive mode of transport. In fact, the cost of its operation is very high and, thus, it is the most suitable for carrying goods of high-value or time-sensitive emergency shipments that have to travel a long distance.

Package carriers are transportation companies which use air, truck, and rail to transport time-sensitive smaller packages. It is an expensive mode that offers a rapid and reliable delivery. Package carriers are the preferred mode of transport for e-businesses, as well as for companies that send small packages to customers.

Rail or railway transport is the cheapest, quickest and best suited for carrying heavy, bulky and not very time sensitive goods over long distances.

Truck transport is more expensive than rail but offers the advantage of direct shipment and a shorter delivery time. This mode can be easily combined with other modes of transport. The trucking industry consists of two major segments: TruckLoad and less than TruckLoad.

TruckLoad is suited for large shipping even between manufacturing facilities and warehouses or between suppliers and manufacturers. It is also a considerable faster mode to transport products with not having the driver stop for multiple pickups or having to load and unload freight throughout the trip.

Less than TruckLoad is appropriate to transport shipments in small lots. Less than TruckLoad shipments take longer than TruckLoad shipments because of other loads that need to be picked up and dropped off. It is the most cost-effective way to transport products because of the high degree of consolidation that carriers can achieve for the loads carried.

Water transport is suited for carrying very large and bulk loads at low cost. It is, however, the slowest of all the modes, and significant delays occur at ports and terminals.

The pipeline mode is used for the transport of crude petroleum, refined petroleum products, and natural gas, phosphate. It is the best suited when relatively stable and large flows are required.

Intermodal transportation is the use of more than one mode of transport to transport products.

3.1.2 Design options for a transportation network

There are a variety of design options for transportation network (Chopra and Meindl, 2003). They include the six options given below:

1. Direct shipment network: the products are shipped directly from suppliers to customers. It is suited for large shipments that require TruckLoad shipping, or when the delivery time can be a critical factor.
2. Direct shipping with milk-runs: the deliveries are either shipped directly on a truck from one supplier to multiple customers, or are pick up on a truck from many suppliers to one customer.
3. All shipment via central distribution centre (DC) with inventory storage: products are shipped to customers via distribution centre which is built for each region of the country. The products are held in inventory at the distribution centre.
4. All shipment via central DC with cross-dock: products arrive from many suppliers into inbound trucks to be transformed into smaller shipments that are then loaded

onto trucks going to each customer. It is suited for products with large, predictable demands, or for sensible products that need to be quickly transported.

5 Shipping via DC using milk-runs: products are shipped from suppliers to distribution centres to be then transported on milk-run to each customer by consolidating small shipments.

6 Tailored network: the use of different transportation network structures based on customer and product characteristics.

3.2 Designing the distribution network: location-allocation problem

The design of the distribution network is a strategic issue for almost every chain. The location-allocation problem covers the core topics of distribution network design (Klose and Drexl, 2005). It is used to determine the best locations of various facilities, the allocation of customer demands to them and to find the optimum flows of products from these facilities to different points of demand (customers) (Chopra and Meindl, 2003).

Location-allocation decisions have a long-term impact on a supply chain's performance. A good facility location-allocation decisions can help a supply chain to be more responsive and efficient (Chopra and Meindl, 2003).

As a result, it is very important for the decision-makers to select the appropriate decisions about the location-allocation problem.

The location of facilities and the allocation of customer demands to them have been a substantial research area. The study of location-allocation problems stretches back to 1960s when (Cooper, 1963) proposed the basic facility location-allocation problem. Since then, this problem has become a contentious issue of debate among scientists and researchers. A large number of studies on location-allocation problems have been conducted in the literature; for instance, incapacitated single allocation planar hub location problem (Damgacioglu et al., 2015), continuous multi-facility location allocation problem (Dinler et al., 2014), multi-period location-allocation problem of engineering emergency blood supply systems (Sha and Huang, 2012), multi-source facility location-allocation and inventory problem (Yao et al., 2010), a dynamic multi-period location-allocation problem (Gebennini et al., 2009) and a multi-objective facility location-allocation problem (Arabzad et al., 2015).

Literature about facility location-allocation in supply chain design is extensive and diverse. Historically, cost or distance minimisation has been the basis factor for location-allocation problems. However, researchers have long realised that solving location-allocation problem based on this single objective could be detrimental to the supply chain's performance. Hence, they have suggested the consideration of multiple objectives in solving location-allocation problem, and they have affirmed that the majority of location-allocation problems are multi-objective in nature (Klose and Drexl, 2005).

Many supply chain managers and researchers have realised that the location-allocation decisions are extremely linked to transportation ones. Shen et al. (2015) considered location and transportation decisions simultaneously as a kind of transportation-location problem; they have proposed a multi-objective programming model based on a network flow model to assist decision makers in analysing combined path/location decision. Nagy and Salhi (2007) added that location-allocation problem and transportation one are closely interrelated, as shelter locations directly influence the routing options available, and available routes affect the locations of potential shelter in return. They classified this problem as multi-objective transportation-location mathematical programming problem.

Furthermore, Hamadani et al. (2013) added that the effective choice of the appropriate transportation management and location facilities is an important task for a proper management of the whole supply chain. In other work of Melkote and Daskin (2001), they investigated a mathematical model that simultaneously optimises facility locations and the design of the transportation network. Moreover, Cappanera et al. (2003) added that the facility location and transportation logistics decisions are strictly interrelated while proposing a facility location routing problem. Also, Melo et al. (2009) affirmed that transportation decisions are extremely related to location-allocation ones.

Therefore, in order to design a logistic network structure that facilitates the arising goods flows in an optimal way, the location-allocation and transportation decisions need to be taken simultaneously.

The analysis of the literature has shown that the majority of the studies combine the problem of location-allocation with that of transporting goods between supply and demand points while using the mathematical modelling to formulate the combined problem. However, in our work, we propose to first determine the optimal location allocation decisions through mathematical programming resolution and then choose the most appropriate transportation network design option that may suit the supply chain distribution structure.

4 Framework for designing a transportation network for a supply chain

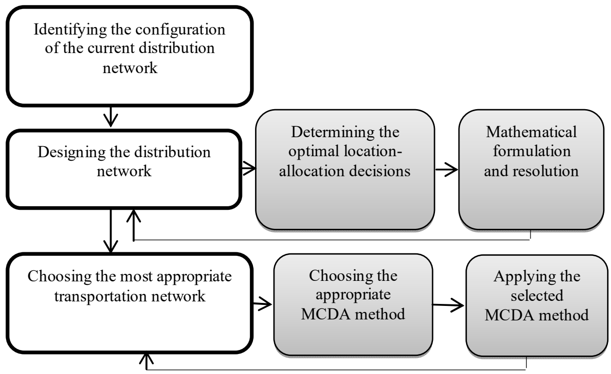
Based on the literature review, we develop a framework for designing a transportation network for a supply chain while taking into account the distribution network design decisions.

The purpose of this paper is to introduce a framework for designing a transportation network for a pharmaceutical supply chain. As depicted in Figure 1, the framework is defined in three steps:

1. identifying the configuration of the current distribution network
2. determining the optimal location-allocation decisions for the current distribution network
3. choosing the most appropriate transportation network design option that may suit the supply chain distribution network structure.

To deal with the second step, the supply chain’s location-allocation problem can be modelled as a mathematical programming formulation taking into account the conflicting objectives that the decision-makers need to meet. While, the third step deals with the choice of the most suitable transportation network structure given the supply chain’s distribution network among different transportation network alternatives. Each of the transportation network design options has its own inherent strengths and weaknesses. Based on different performance criteria, these transportation structures alternatives will be ranked from the most appropriate to least appropriate in order to find the most proper transportation network design option for the supply chain's distribution network while applying the appropriate multi-criteria decision analysis (MCDA) method.

Figure 1 Framework for designing a transportation network



MCDA methods have been developed to support the decision-maker in their decision process while prioritising or selecting one or more alternatives from a set of available alternatives with respect to multiple conflicting criteria (Hyde, 2006). They provide stepping-stones and techniques for finding a compromise solution (Ishizaka and Nemery, 2013). MCDA is a discipline that encompasses several disciplines, e.g., mathematics, management, informatics, social science and economics. Its application is even broader as it can be used to solve any kind of problem where an important decision needs to be made (Ishizaka and Nemery, 2013).

Generally, decision makers face a plethora of different decisions. Roy (1981) has identified four main types of decision, these include:

1 The choice problem which consists on choosing the best option or reducing the group of options to a subset of equivalent good options.

2 The sorting problem where the options with similar characteristics are regrouped for descriptive, organisational or predictive reasons.

3 The ranking problem where the alternatives are ranked from best to worst by means of scores or pairwise comparisons.

4 The description problem which consists on describing options in order to understand the characteristics of the decision problem. In paper, we are interested in the choice problems.

The most popular MCDA methods that are used in solving the choice problems, which we are interested in, are the analytic hierarchy process (AHP) (Saaty, 1980), analytical neural process (ANP) (Saaty, 2005), the multiple attribute utility theory (MAUT) (Keeney and Raifa, 1976), preference ranking organisation method for enrichment evaluations (PROMETHEE) (Brans and Vincke, 1985), the elimination et choix traduisant la realité (ELECTRE) (Roy and Vincke, 1981), the technique for order preference by similarity of ideal solution (TOPSIS) (Hwang and Yoon, 1981). Each method has its own limitations, particularities, hypotheses and perspectives. This great diversity of MCDA methods makes the choice of one method rather than another one, in a specific problem situation, an arduous task for decision makers (Ishizaka and Nemery, 2013).

There are different ways of choosing appropriate MCDA methods to solve specific problems. Guitouni and Martel (1998) suggested a framework to help in choosing an appropriate MCDA method. They proposed seven tentative guidelines, based on a comparative study of different MCDA methods, to choose to appropriate method. Teghem and Delhaye (1989) proposed a decision tree which is constructed along some assumption on the ranking of the questions to be put to the decision maker. De Montis et al. (2004) presented a comparative study of seven different MCDA methods based on a list of quality criteria which provides a basis to assess the usefulness of each method for a specific application. De Montis et al. (2000) suggested some guidelines to help in choosing the appropriate MCDA Method that best suits the requirements of the problem at hand.

On the basis of the research literature on MCDA methods, we will give at a later stage some characteristics that must be verified to select the appropriate MCDA method according to the decision problem.

5 Adopting a transportation network for the Moroccan public pharmaceutical supply chain

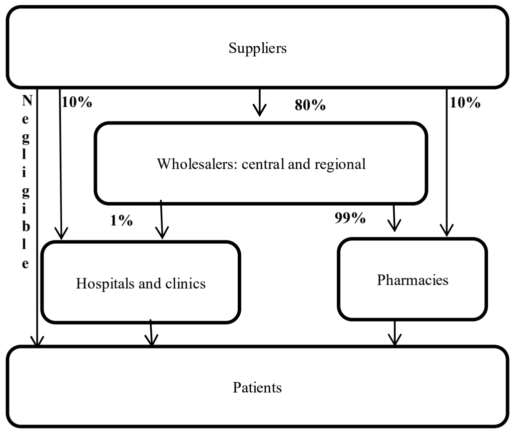
In this section, we apply our suggested framework to design a transportation network of the public sector pharmaceutical products supply chain in Morocco. First, we identify the configuration of the Moroccan's current distribution network of pharmaceutical products. Second, we fine-tune the current design by determining the appropriate location-allocation decisions. Finally, we choose the appropriate transportation network of pharmaceutical products.

5.1 Step 1: identifying the configuration of the current distribution network

The distribution of pharmaceutical products in Morocco is done through two main channels: direct and indirect channels as shown on Figure 2 (Organization for Economic Co-operation and Development, 2014).

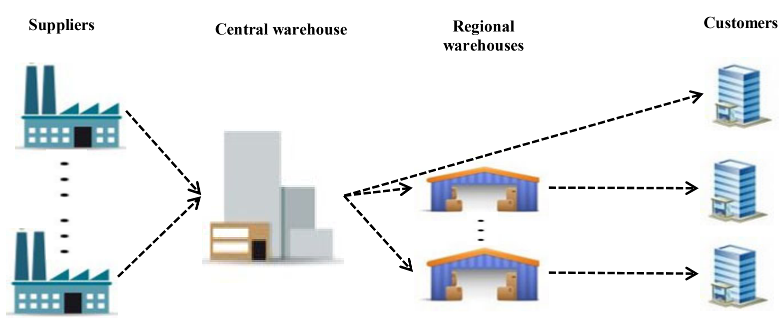
- *Direct channel*: pharmaceutical products are directly transported from laboratories to provincial hospital and pharmacies and to hospital and healthcare institutions (Organization for Economic Co-operation and Development, 2014).
- *Indirect channel*: pharmaceutical products are transported through wholesalers in order to supply pharmacies and any other entity. This is the principal channel and accounts for 80% of the market (Organization for Economic Co-operation and Development, 2014).

Figure 2 Pharmaceutical products distribution circuit



Source: Moroccan Pharmaceutical Industry Association (AMIP) based on IMS health figures (Organization for Economic Co-operation and Development, 2014)

Figure 3 Schema of Moroccan pharmaceutical supply chain (see online version for colours)



In the Moroccan public sector, pharmaceutical products are transported from suppliers to the storage sites of the Moroccan Ministry of Health, which are divided into central and regional warehouses. The Central warehouse usually has copious storage capacity and it is in charge of delivering the received products, either directly or via regional warehouses, to the customer zones including provincial and regional hospitals (CHP and CHR) and provincial delegations (PD) (Moroccan Ministry of Health, 2014) (see Figure 3).

5.2 Step 2: fine-tuning the current distribution network: location-allocation problem

The importance and significance of location-allocation decisions in healthcare sector cannot be overemphasised when providing availability and accessibility of essential pharmaceutical products for all the population at the right time and place continues to be a key concern of most countries. In this field, several researchers have presented different models for location-allocation of healthcare facilities. Zahiri et al. (2014) proposed a multi-period location-allocation model for the design of an organ transplant network under uncertainty. It consists of a bi-objective mathematical programming model that minimises total cost and time; they used two metaheuristics for solving the mathematical model. Zhang and Jiang (2013) presented a bi-objective robust programming approach for an emergency medical services system (EMS) under uncertainty that minimises the total costs and determines the assignment of demand points to EMS, location of EMS facilities, and the number of EMS vehicles at each station. More recently, a bi-objective mixed-integer programming model for the multi-period location-allocation problem of the pharmaceutical supply chain was developed by Mousazadeh et al. (2015) in order to minimise the total cost and unsatisfied demands. Then, they applied a robust possibilistic programming approach to deal with the uncertainty of critical data, they used two different multi-objective decision making methods to solve the problem.

Moreover, location-allocation problems arising in developing countries have been discussed by several authors. Izadi and Mohammad Kimiagari (2014) designed a distribution network design under demand uncertainty for a pharmaceutical distribution companies in Iran. They used genetic algorithm and Monte Carlo simulation approach for solving the mathematical model. Shariff et al. (2012) proposed a new solution approach based on genetic algorithm to solve capacitated maximal covering healthcare location-allocation problem and applied it to one of the districts of Malaysia. Murawski and Church (2009) proposed an integer-programming to improve the health service accessibility's problem in Ghana by upgrading links to the existing facility locations of the transport network to all-weather roads. This model is adequate for rural areas of under-developed countries where, during bad weather conditions, accessibility is diminished because of the lack of all-weather roads. Ares et al. (2016) proposed a column generation approach for locating roadside clinics in Africa based on effectiveness and equity.

In our case, we use a mixed integer programming to formulate the location-allocation problem of the Moroccan public pharmaceuticals supply chain. We take as a starting point the mathematical model for a multi-echelon supply chain network design problem developed by Shankar et al. (2013) to formulate our problem.

The traditional mathematical programming formulation of the location-allocation problem considers only the economic aspect which is the total cost minimisation, while there are other important factors that should not be left outside the analysis such as the maximisation of customer service levels. The developed model consists of a bi-objective mathematical programming model that makes possible a trade-off analysis between two important objectives which are the minimisation of the total cost and the improvement of customer service levels by maximising the fill rate defined as the fraction of customer demand satisfied.

The proposed bi-objective mathematical model can be described as follows. There are I suppliers including laboratories and suppliers of medical equipment, J central warehouses, K regional warehouses and C customer zones including the provincial and regional hospitals (CHP and CHR) and the PD.

The objective function Z_1 minimises the cost of a supply chain including the establishment cost of central and regional warehouses and transportation costs. The objective function Z_2 maximises the customer service level by maximising the fill rate. Constraint (1) specifies that the total quantity of products shipped from a supplier cannot exceed the supplier's capacity. Constraint (2) states that the quantity shipped out of a central warehouse cannot exceed the quantity of products received. Constraints (3) and (5) state that no warehouse can supply more than its capacity. Constraint (4) specifies that the quantity of products transported from a regional warehouse cannot exceed the quantity of products received. Constraint (6) requires that the demand of each customer zone be satisfied to the maximum extent. Constraints (7) and (8) ensure that each central or regional warehouse can only have one capacity level. Constraint (9) states that fill rate exceeds 0, 8.

In this paper, we will not solve the proposed model due to the unavailability of required data; however, solving this mathematical model will be the subject of our future work.

Indices

i index for suppliers ($i = 1, \ldots, I$).

j index for central warehouses ($j = 1, \ldots, J$).

k index of regional warehouses ($k=1, \ldots, K$).

c index of customer zones including the provincial and regional hospitals (CHP and CHR) and the PD ($c = 1, \ldots, C$).

m index of pharmaceutical products ($m = 1, \ldots, M$).

n index of the capacity level of central warehouses ($n = 1, \ldots, N$).

r index of the capacity level of regional warehouses ($r = 1, \ldots, R$).

Parameters

D_{ijm} unit transportation cost of product m from supplier i to central warehouse j.

T_{jkm} unit transportation cost of product m from central warehouse j to regional warehouse k.

A_{jcm} unit transportation cost of product m from central warehouse j to customer zone c.

B_{kcm} unit transportation cost of product m from regional warehouse k to customer zone c.

E_{jn} establishing cost of central warehouse j in capacity level n.

F_{kr} establishing cost of regional warehouse k in capacity level r.

dmc demand of product m in customer zone c.

h_{jn} storage capacity of central warehouse j established by the capacity level n.

o_{kr} storage capacity of regional warehouse *k* established by the capacity level *r*.

S_i supplier capacity at supplier *i*.

Variables

W_{ijm} quantity of products *m* shipped from supplier *i* to central warehouse *j*.

Q_{jcm} quantity of products *m* shipped from central warehouse *j* to customer zone *c*.

U_{jkm} quantity of products *m* shipped from central warehouse *j* to regional warehouse *k*.

V_{kcm} quantity of products *m* shipped from regional warehouse *k* to customer zone *c*.

x_{jn}, y_{kr} binary variables.

$x_{jn} = 1$ if central warehouse *j* with capacity level *n* is opened; and 0 if not.

$y_{kr} = 1$ if regional warehouse *k* with capacity level *r* is opened; and 0 if not.

Mathematical model

$$Min\ Z_1 = \sum_{j,n} E_{jn}.x_{jn} + \sum_{k,r} F_{kr}..y_{kr} + \sum_{i,j,m} D_{ijm}.W_{ijm} + \sum_{j,c,m} A_{jcm}.Q_{jcm} + \sum_{j,k,m} T_{jkm}.U_{jkm} + \sum_{k,c,m} B_{kcm}.V_{kcm}$$

$$Max\ Z_2 = \left(\sum_{c,m}\left(\sum_{j,k}\left(Q_{jcm} + V_{kcm}\right)\right)\right) \Big/ \sum_{c,m} d_{mc}$$

s.t.

$$\sum_{j,m} W_{ijm} \le S_i \quad \forall i \tag{1}$$

$$\sum_{k,m} U_{jkm} + \sum_{c,m} Q_{jcm} \le \sum_{i,m} W_{ijm} \quad \forall j \tag{2}$$

$$\sum_{k,m} U_{jkm} + \sum_{c,m} Q_{jcm} \le \sum_{n} h_{jn}.x_{jn} \tag{3}$$

$$\sum_{c,m} V_{kcm} \le \sum_{j,m} U_{jkm} \quad \forall k \tag{4}$$

$$\sum_{c,m} V_{kcm} \le \sum_{r} o_{kr}..y_{kr} \quad \forall k \tag{5}$$

$$\sum_{k,m} V_{kcm} + \sum_{j,m} Q_{jcm} \le d_{mc} \forall c \tag{6}$$

$$\sum_{n} x_{jn} \le 1 \quad \forall j \tag{7}$$

$$\sum_{r} y_{kr} \leq 1 \quad \forall k \tag{8}$$

$$\left(\sum_{c,m} \left(\sum_{j,k} \left(Q_{jcm} + V_{kcm} \right) \right) \right) \Big/ \sum_{c,m} d_{mc} \geq 0.8 \tag{9}$$

$$x_{jn}, y_{kr} \in \{0, 1\} \quad \forall j, k, n, r \tag{10}$$

$$x_{jn}, y_{kr}, U_{jkm}, V_{kcm}, W_{ijm}, Q_{jcm} \geq 0 \quad \forall i, j, k, c, n, m, r \tag{11}$$

For the next step of the suggested framework we will adopt the current Moroccan public distribution network of pharmaceutical products to choose the most appropriate transportation network option.

5.3 Step3: choosing the most appropriate transportation network design option

In order to design a well-handled transportation network of pharmaceutical products that meets customer demand in the most effective and efficient way, it is necessary to choose the appropriate transportation structure for the Moroccan's current distribution network of pharmaceutical products among four different alternatives presented in Table 1 while applying the appropriate MCDA method. These alternatives have been derived from the six options suggested in Chopra and Meindl (2003) taking into account the current structure of the distribution network.

5.3.1 Presenting alternatives

Based on the different transportation structures given by Chopra and Meindel (2003). We propose four transportation network design options for the Moroccan's current distribution network as shown in Table 1.

5.3.2 Determining selection criteria

The choice of the appropriate transportation network design option of pharmaceutical products is based on a set of criteria (*Cj*). Some of those criteria are determined according to Chopra and Meindl (2003) and others are related to the pharmaceutical sector. These include:

1 *Criteria to minimise*
   - Delivery time: the actual time between placing an order, and receiving the delivered product.
   - Number of trucks: the use of milk-run reduces the number of trucks utilised for shipping pharmaceutical products.
   - Transportation cost: consolidating shipments lowers transportation cost.
   - Information system cost: the use of milk-runs increases the cost of information system because it requires a significant degree of coordination.

Table 1 Transportation network design options

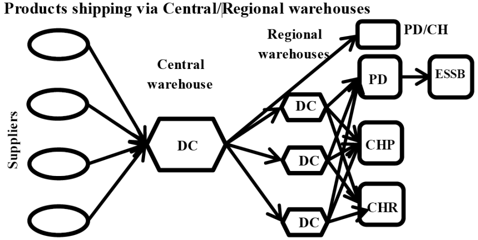
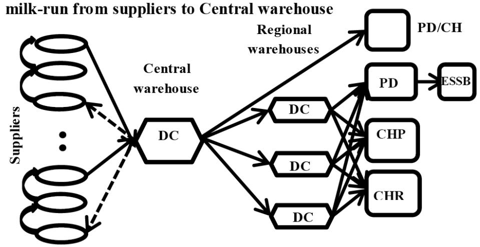
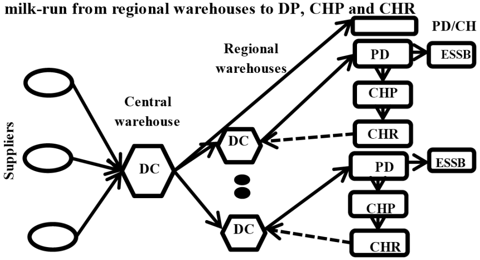
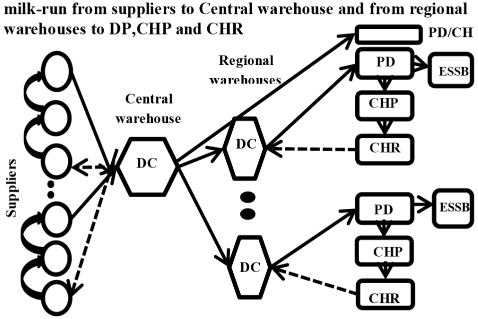
Transportation network design options	*Description*	*Strengths*	*Weaknesses*
Products shipping via Central/Regional warehouses 	Products arrive from many suppliers into inbound trucks to the central warehouse to be then loaded onto trucks going either directly to the supply chain's customer or via regional warehouses.	• Decreased transportation cost through consolidation	• Increased inventory cost • Increased handling at central/regional warehouses
Products shipping via Central/Regional warehouses with using milk-run from suppliers to Central warehouse 	The deliveries are pick up on a truck from many nearly suppliers to the central warehouse, then the products are shipped to supply chain's customers either directly or via regional warehouses.	• Decreased transportation cost • Reduce the number of trucks utilised for shipping pharmaceutical products • Reduce the number of truck's empty return	• Increased inventory cost • Increased coordination complexity • Increased handling at central/regional warehouses

Table 1 Transportation network design options (continued)

Transportation network design options	*Description*	*Strengths*	*Weaknesses*
Products shipping via Central/Regional warehouses with using milk-run from regional warehouses to DP, CHP and CHR 	Products arrive from many suppliers into inbound trucks to the central warehouse to be then loaded onto trucks going either directly to the supply chain's customers or via regional warehouses where the products are shipped to multiple nearly supply chain's customers with using a single truck.	• Decreased inbound transportation cost through consolidation • Reduce the number of trucks utilised for shipping pharmaceutical products • Reduce the number of truck's empty return • Decreased handling cost at regional warehouses	• Increased inventory cost • Increased coordination complexity • Increased handling at central warehouse
Products shipping via Central/Regional warehouses with using milk-run from suppliers to Central warehouse and from regional warehouses to DP,CHP and CHR 	It is a combination of the second and the third transportation option where the deliveries are pick up on a truck from many nearly suppliers to the central warehouse to be then shipped either directly to the supply chain's customers or via regional warehouses where the products are then loaded onto single truck going to multiple nearly supply chain's customers.	• Lower transportation cost through consolidation • Lower handling cost • Reduce the number of trucks utilised for shipping pharmaceutical products • Reduce the number of truck's empty return	• Increased inventory cost • Increased coordination complexity

2 *Criteria to maximise*

- Regulatory criteria: each activity in the transportation of pharmaceutical products should be carried out according to requirements of the drugs act and to the appropriate transportation in order to avoid the risk of exposure the pharmaceutical products to temperatures outside labelled storage conditions, potentially impacting the safety, quality and effectiveness of the pharmaceutical products.

In the following, we choose the appropriate MCDA method to apply, in order to determine the best transportation network alternative.

5.3.3 Choosing the appropriate MCDA method

Considering the fact that the transportation network design selection problem concerns a discrete set of alternatives that are evaluated against criteria measured on different and non-commensurate scales of measurement, we address – in this section – the choice problem of the appropriate discrete MCDA method. Several research studies have been conducted concerning the choice of discrete MCDA methods (Guitouni and Martel, 1998; Chan and Costa, 1993; Hwang and Yoon, 2012; Pardalos et al., 2013).

These methods can be divided into three operative approaches:

a methods based on the use of a single synthesising criterion

b methods based on the synthesis by outranking

c methods based on interactive local judgements (Roy, 1996). In paper, we are interested in the first two groups.

To ease the selection of the appropriate MCDA discrete method, we were inspired by the work of Guitouni and Martel (1998). They have proposed seven general principles or guidelines to help to choose an appropriate MCDA method, these include:

Guideline 1 Determine the stakeholders involved in the decision process.

Guideline 2 Consider the decision-maker way of thinking when choosing a particular preference evaluation mode.

Guideline 3 Determine the decision making problematic pursued by the decision maker.

Guideline 4 Choose the method that can manage correctly the input information.

Guideline 5 Consider the compensation degree of the MCDA method, if the decision-maker refuses any compensation, then a variety of MCDA methods will not be considered.

Guideline 6 Verify the fundamental hypothesis of the method.

Guideline 7 Consider the decision support system coming with the MCDA method.

The first guideline determines the stakeholders to be involved in the process in order to help in determining the MCDA method. We supposed, in our case, that the problem is concerned with one decision-maker. The second guideline concerns the preference evaluation modes, there exist different modes used by the MCDA methods which are: trade-offs, lotteries, direct rating and pairwise comparisons, each mode has its advantages and disadvantages (Guitouni and Martel, 1998; Ishizaka and Nemery, 2013). It is very important to consider the decision-maker way of thinking when choosing a particular preference evaluation mode. In our case, we chose the pairwise comparison as it is a good elucidation mode (Guitouni and Martel, 1998). The third guideline concerns the decision problematic persuade by the decision maker. As we already mentioned, we are interested in choice problem. The fourth guideline deals with the different kinds and features of the input information. This information can be expressed as cardinal or ordinal, uncertain or certain, mixed (Guitouni and Martel, 1998). The input information, in our case, is expressed as cardinal and uncertain. The fifth guideline investigates the compensation degree of the method as it's an important aspect to be explained to the decision maker in choosing the appropriate MCDA Method. We supposed, in our case, that some kind of compensation is accepted between the different dimensions of the problem. The sixth guideline concerns the verification of the MCDA method's hypothesises which are as follow: the independence, the transitivity, the dominance, the invariance, commensurability and transitivity (Guitouni and Martel, 1998). Finally, the seventh guideline determines whether a method is supported by a decision support system or not.

Thus, the different methodological principals or guidelines, on which we have been based, in choosing the appropriate discrete MCDA method according to our choice problem are as follows:

C1 Weighting assessment mode: trade-offs (T), direct rating (DR) or pairwise comparison (PC).

C2 Type of input information: ordinal (O), cardinal (C) or mixed (M).

C3 Information features: determinist (D), non-determinist (ND).

C4 Compensation degree: totally (T), partially (P).

C5 MCDA method's hypothesizes: independence (I), the dominance (D), the invariance (In), commensurability(C) and transitivity (T).

C6 existence of software package: yes (Y) or no (N).

Furthermore, we have chosen the following methods as they are the most used discrete MCDA methods in selection problems. These include: the AHP (Saaty, 1980), ANP (Saaty, 2005), the MAUT (Keeney and Raifa, 1976), PROMETHEE (Brans and Vincke, 1985), ELECTRE (Roy and Vincke, 1981), the TOPSIS (Hwang and Yoon, 1981) and evaluation of mixed data (EVAMIX) (Voogd, 1983).

To ease the selection of the appropriate MCDA discrete method, we present a comparison table (Table 2) that illustrates the different methodological principles previously described.

Comparing the MCDA methods according to the different methodological principles previously described (Guitouni and Martel, 1998), several points have been generated. Starting from TOPSIS, it allows a direct rating of alternatives depending on data in the evaluation matrices and weights. One of the positive features of the method consists in the simplicity and flexibility of use, the easily understandable procedure based on the geometric representation (Caterino, 2008). However, it has some disadvantages, such as correlations between criteria, possibility of alternative closed to ideal point and nadir point concurrently (Xu et al., 2015), the performance ratings and the weights of the criteria are given as exact values, but in real-world situation, because of incomplete or non-obtainable information, the data are often not deterministic (Izadikhah, 2012). Moreover, TOPSIS has been criticised because it sometimes gives illogical results (Ishizaka and Nemery, 2013).

Concerning MAUT, it is a particular useful method when the utility function for each criterion is known. However, the construction of the utility function requires a lot of effort. Moreover, only situations in which the evaluations of the alternatives are defined with certainty will be considered (Ishizaka and Nemery, 2013).

Table 2 Comparison of MCDA methods on the basis of C1, C2, C3, C4, C5 and C6

Discrete MCDA methods		*C1*			*C2*			*C3*	
		T	*DR*	*PC*	*O*	*C*	*M*	*D*	*ND*
Single synthesising criterion methods	AHP			✓		✓		✓	✓
	ANP			✓		✓		✓	✓
	TOPSIS		✓			✓		✓	
	MAUT	✓				✓		✓	
Outranking methods	PROMETHEE			✓	✓	✓	✓	✓	
	ELECTRE			✓	✓	✓	✓	✓	

Discrete MCDA methods		*C4*		*C5*					*C6*	
		T	*P*	*I*	*D*	*In*	*C*	*T*	*Y*	*N*
Single synthesising criterion methods	AHP		✓	✓	✓	✓			✓	
	ANP		✓		✓	✓			✓	
	TOPSIS	✓		✓	✓	✓	✓	✓		✓
	MAUT		✓	✓	✓	✓		✓	✓	
Outranking methods	PROMETHEE		✓	✓		✓			✓	
	ELECTRE		✓	✓		✓			✓	

Source: According to Guitouni and Martel (1998)

The next group of methods is the PROMETHEE and ELECTRE, they are an outranking methods that performs pairwise comparisons among the alternatives for each one of the criteria separately to establish outranking relationships between them. It has been seen that a positive feature of these methods consists in the capability to manage non-homogeneous variables and different types of input information (Caterino, 2008). However, the main disadvantages are their expenditure in time, their complex application and the difficulty to keep an overview over the problem when a lot of criteria are involved (Gavade, 2014).

The AHP method, among those considered seems to be the most appropriate to apply. In fact, the transportation network selection problem concerns a discrete set of alternatives under uncertainty. The AHP method can effectively deal with different types of information features; deterministic as well as non-deterministic (Guitouni and Martel, 1998). Furthermore, throughout this method, the hierarchy is revealed after the breakdown of the problem, which enables understanding and defining the process itself (Kolios et al., 2016). In addition to this, the use of AHP does not involve complex mathematics (Charilas et al., 2009). Designed to reflect the way people actually think, AHP continues to be the most highly regarded and widely used decision-making method because of its flexibility and its ability to check inconsistency (Gavade, 2014). In addition, the AHP method uses the pairwise comparison mode which has been proven to be a good mode to use in evaluating the preferences of the decision-makers (Guitouni and Martel, 1998). It should be noted that AHP cannot directly consider the dependencies between criteria. In this regard, an extension of AHP has been proposed that effectively deal with dependency which is ANP (Kolios et al., 2016).

The AHP, first developed by Saaty (1980), is a multi-criteria decision analysis method (MCDA) that allows an analysis of complex multi-criteria decision problems while providing an objective methodology for deciding among a finite set of alternatives for solving that problem (Baran and Żak, 2014). The AHP method is one of the most widely used MCDA method in several and different fields to evaluate, compare, and rank different options, and it has been typically applied in transportation issues (de Luca, 2014; Quadros and Nassi, 2015).

Several researchers have attempted to use the AHP method for different transportation problems. Yedla and Shrestha (2003) applied the AHP for the selection of alternative options for environmentally sustainable transport system in Delhi. In addition, (Piantanakulchai and Saengkhao, 2003) used the AHP method for the evaluation of alternatives in transportation planning. Zeng et al. (2007) has also used AHP in the evaluation and selection of suppliers for transportation. Also, Tabucanon and Lee (1995) used the AHP method to evaluate the transportation system improvement project in Korea.

Table 3 Scales of relative importance

Intensity of importance	*Definition*
1	Equal importance
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred
2,4,6,8	Intermediate values

Source: According to Saaty (1980)

Table 4 Random coherence index

N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Source: According to Saaty (1980)

The basic principles of AHP method can be summarised in the following steps:

Step 1 Decomposing the problem in a hierarchy from the overall goal of the evaluation process through the criteria and sub criteria, until the alternatives to be evaluated.

Step 2 Constructing pairwise comparison matrices for each element at each level of the hierarchy above using the relative scale measurement shown in Table 3. These pairwise comparisons are used to derive priorities of each element at each level.

Step 3 Applying the principle of hierarchic synthesis to multiply the priorities of elements by the global priority of the parent element, producing global priorities throughout the hierarchy and then adding the global priorities for the lowest level elements of the hierarchy (the alternatives).

Step 4 Calculating the consistency ratio (CR) to verify the level of coherence of the judgement, CR is calculated: $CR = CI/RI$. Where CI is the consistency index, calculated by using the eigenvalue, λmax, as follows: $CI = (\lambda\text{max} - n)/(n - 1)$. RI is the random CI, extracted from the random CI table given by Saaty (1980) (see Table 4). If the $CR > 0.1$ the judgements are untrustworthy.

5.3.4 Selecting the proper transportation network design option

In the following, we applied the steps of AHP method which are previously described to select the most appropriate transportation network for the Moroccan's current distribution network.

The comparison of the different transportation network alternatives across criteria has been done according to the literature in order to illustrate the use of AHP in selecting the appropriate transportation structure. However, it should normally be based on the preferences of decision-makers.

Below, we discuss and clarify the assumptions behind the choice of preferences in comparing the transportation network alternatives against each criterion.

In our future work, however, the choice of the appropriate transportation network will be done after the determination of the optimal distribution network while solving the location-allocation mathematical model.

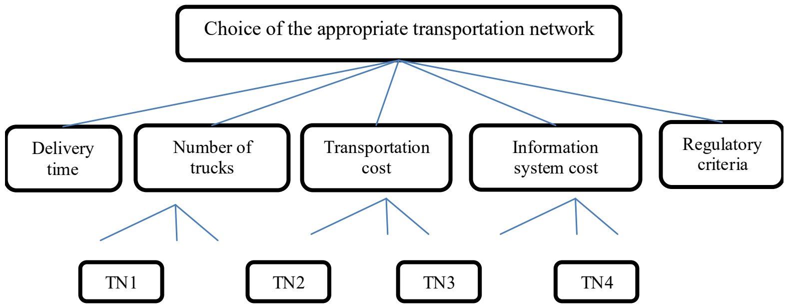
Step 1 Presenting the hierarchy

Figure 4 shows the hierarchical structure of the problem. Starting with the top level, the global goal is to choose the most appropriate transportation network. In the subsequent level, we present the evaluation criteria. And finally in the last level, the different transportation network alternatives (TNi) from which we will be able to choose the best transportation network alternative.

Step 2 Matrices and calculation

After establishing the hierarchy, the next step is to set pairwise comparison matrices of order 4 for comparing the transportation network alternatives against each criterion. Next, we calculate the priority vector of each transportation network alternative according to the selected criterion by calculating the geometric mean and dividing each row by the total means. Finally, we calculate the eigenvalue (λmax), the CI, and the CR for each pairwise comparison matrix.

Figure 4 Hierarchy of decision (see online version for colours)



The comparison of the different transportation network alternatives across criteria should be based on the preferences of decisions makers. However, and because of lack of data to determine the optimal distribution network and then conduct of a survey of the pharmaceutical supply chain stakeholders in Morocco, we discuss according to the literature the assumptions behind the choice of preferences in comparing the transportation network alternatives against each criterion in order to illustrate the use of AHP in selecting the appropriate transportation structure. The common point between the four transportation network alternatives is the application of the milk-run method.

- do not apply milk-run in the product shipping (TN1)
- applying milk-run in the products shipping from suppliers to central warehouse (TN2)
- applying milk-run in the products shipping from regional warehouses to customers (TN3)
- applying milk-run from suppliers to central warehouse and from regional warehouses to customers (TN4).

Thus, the comparison of these four options against criteria comes down to the study of the impact of applying milk-run method, with respect to these criteria, on the transport network. In this field, several researchers have pointed up the importance of applying Milk-run in achieving an effective delivery system (Chopra and Meindl, 2003; Setiani et al., 2018). Concerning transportation cost and number of trucks, the use of milk-run allows deliveries to multiple locations to be consolidated on a single truck, or to be pick up from many nearly suppliers into single truck to the same location. So, the vehicle can be make full use of space, greatly improve the vehicle's load factors, and avoid the waste of empty vehicles, resulting in better utilisation of the truck and somewhat lower transportation cost (Chopra and Meindel, 2003; Setiani et al., 2018; Kovacs, 2011). For this reason, we have adopted, in relation to these two criteria this ranking (TN4, TN3, TN2, TN1). However, using milk-run in products shipping requests logistic centre and each distribution point to fully share information, resulting a significant degree of coordination so an increase of the cost of information system. That is why we have adopted, regarding the information system cost criteria, the following ranking (TN1, TN2, TN3, TN4).

In the process of milk-run, the delivery time will be delayed because products will not be going directly from suppliers to customers (You and Jiao, 2014). Thus, we have prioritised regarding delivery time criteria the alternatives where the milk-run is not applied between central/regional warehouses and customers. As a result the products can be delivered faster without having to wait for other customers. However, several works have concluded that milk-run method delivery enables to minimise delivery time by finding the optimal route to get the best route combination by integrating several nearly suppliers into one route within the capacity of trucks' total delivery volume (Setiani et al., 2018). In fact, using milk-run can reduce the delay to deliver the product by reducing the period that the product could stay in the storage centre while the others product be supplied so the order will be delivered, shorten the distribution distance through effective path planning, and avoid the waste of time on the way (You and Jiao, 2014). As a result, we have adopted regarding the delivery time criteria the following ranking (TN2, TN1, TN4, TN3).

Furthermore, applying milk-run in the transport of pharmaceuticals remains a good idea. In fact, using milk-run reduce the inventory storage level so the pharmaceutical products will not be stored for a long time which can impact the safety, quality and effectiveness of the PPs. That is why we have adopted, regarding to regulatory criteria, the following ranking (TN4, TN3, TN2, TN1).

As an illustrative example, Table 5 presents pairwise comparison and calculation of the priority vector for each alternative according to the delivery time criterion which is obtained from normalised eigen vector of the matrix. Eigen value λmax from the comparison matrix. CI and CR are consistency index and consistency ratio respectively. For more clarity, we include some part of the computation below Table 5.

Table 5 Pairwise comparison for delivery time

Delivery time	*TN1*	*TN2*	*TN3*	*TN4*	*Priority vector*
TN1	1	1/3	5	3	0.27
TN2	3	1	7	4	0.55
TN3	1/5	1/7	1	1/3	0.06
TN4	1/3	1/4	3	1	0.13

For $n = 4$, λmax = 4, 13, $CI = 0.043$, $CR = 0.047 < 0.1$ OK.

$$\begin{aligned}\lambda max &= (1+3+1/5+1/3)*0.27+(1/3+1+1/7+1/4)*0.55\\&\quad+(5+7+1+3)*0.06+(3+4+1/3+1)*0.13=4.13\end{aligned}$$

$$CI = \frac{\lambda max - n}{n-1} = \frac{4.13-4}{3} = 0.043$$

$$CR = \frac{CI}{RI} = \frac{0.043}{0.9} = 0.047$$

Likewise, the comparison of the different criteria should be based on the preferences of decisions makers. Yet, we have conducted a pairwise comparison of criteria under some assumptions. The main objective of solving a transport problem is the minimisation of the transportation cost/number of vehicles used for transport. However, the problem studied here concerns the transport of pharmaceuticals, which requires an extra level of care to ensure product makes it safely to the final destination. So, the regulatory criterion represents one of the most important criteria that must be taken into consideration when evaluating transportation network alternatives, that is why we have prioritised the transport cost and the regulatory criteria. Moreover, the delivery time is also a critical criteria because the products must be delivered at time to the final destinations. Then, the information system cost was reported to be the least important criteria in evaluating the alternatives. As a result, we have prioritised the criteria as follows: transportation cost (C3), regulatory criteria (C5), delivery time (C1), number of trucks (C2), information system cost (C4). Table 6 shows pairwise comparison for different criteria.

Table 6 Pairwise comparison for the five criteria

Criteria	*C1*	*C2*	*C3*	*C4*	*C5*	*Priority vector*
C1	1	2	1/4	5	1/3	0.15
C2	1/2	1	1/3	3	1/3	0.11
C3	4	3	1	5	2	0.40
C4	1/5	1/3	1/5	1	1/5	0.05
C5	3	3	1/2	5	1	0.29

For $n = 5$, $\lambda\text{max} = 5, 26$, $CI = 0.065$, $CR = 0.058 < 0.1$ OK.

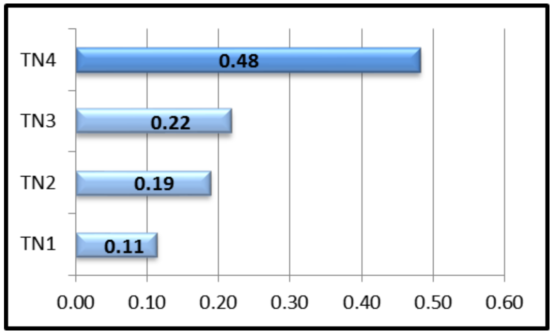
Step 3 Results

The final step of our process is the ‘principle of composition of priorities’. We multiply the criteria weights by the priority vectors of the alternatives for each criterion and sum the respective products. We then choose the alternative with the highest score (see Tables 7 and 8).

Table 7 Criteria weights

Criteria	*Weight*
C1	0.15
C2	0.11
C3	0.40
C4	0.05
C5	0.29

Figure 5 Graph of transportation network options ranking (see online version for colours)



We conclude that TN4 with the highest score of 0.48 is the most appropriate transportation network for the current Moroccan pharmaceutical distribution network (see Figure 5).

Table 8 Priority matrix for transportation network selection

	C1	*C2*	*C3*	*C4*	*C5*	*Overall priority vector*
TN1	0.27	0.05	0.06	0.57	0.06	0.11
TN2	0.55	0.12	0.12	0.24	0.12	0.19
TN3	0.06	0.24	0.26	0.13	0.24	0.22
TN4	0.13	0.59	0.56	0.06	0.58	0.48

6 Conclusions

In this paper, we presented a framework that can help the decision makers in designing a transportation network of a supply chain. It consists of three steps. First, identifying the configuration of the current distribution network. Second, designing a well-handled distribution network while determining the optimal location-allocation decisions. Finally, selecting the most appropriate transportation network design option that may suit the supply chain distribution structure.

We illustrated the application of the suggested framework in designing a transportation network for the Moroccan pharmaceutical supply chain. We have formulated the location-allocation problem as a bi-objective mixed integer programming model which intends to minimise the total cost as well as to maximise the fill rate. For the next step of the framework, we adopted the Moroccan's current public distribution network of pharmaceutical products to choose the most appropriate transportation network design option among different transportation network alternatives through applying the AHP MCDA.

The results showed that applying milk-run option from suppliers to central warehouse, as well as from regional warehouses to customer zones is the most suitable transportation network option for shipping the pharmaceutical products in the Moroccan's current public distribution network.

Future work will deal with determining the optimal location-allocation decisions by solving the bi-objective location-allocation mathematical model. Furthermore, the choice of the appropriate transportation structure for the optimal distribution network determined through the resolution of the location-allocation problem will be done.

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