Journal of Transport and Supply Chain Management
ISSN: (Online) 1995-5235, (Print) 2310-8789

The effect of planning horizon and information sharing on the optimisation of the distribution network of a fast-moving consumer goods supply chain

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Dates:
Received: 25 Apr. 2022
Accepted: 14 May 2022
Published: 28 June 2022

How to cite this article:
Abdallah, K.S. & El-Beheiry, M.M., 2022, 'The effect of planning horizon and information sharing on the optimisation of the distribution network of a fast-moving consumer goods supply chain', *Journal of Transport and Supply Chain Management* 16(0), a788. https://doi.org/10.4102/jtscm.v16i0.788

Background: The distribution network design is very important in optimising the supply chain performance and cost. There are different distribution policies that a company may have to select from, and consequently, the company should plan its resources and should select a planning horizon based on its choice.

Objective: The main objective is to design the distribution network of a fast-moving consumer goods company in order to optimise the transportation and inventory costs by determining the quantities to be shipped and the resources needed. This is analysed throughout different planning horizons and distribution policies.

Method: A mixed integer quadratic problem model is developed to optimise transportation and inventory costs by determining the quantities to be shipped, the quantities to be stored and the types of trucks to be used. The model is applied to four different distribution policies and the performance of each is tested across different time horizons.

Results: An analysis is carried out to optimise the distribution plan for each policy. The effect of the length of the planning horizon on the different plans is also shown.

Conclusion: The results show how each policy performs against the trade-off between the ease of using the policy and its cost of operation. Also, the length of the planning horizon is shown to drastically reduce the total cost and affect the operating conditions when the Vendor Managed Inventory (VMI) policy is considered.

Keywords: production-distribution design; supply chain cooperation; information sharing; supply chain distribution; FMCG; VMI.

Introduction

Distribution of fast-moving consumer goods (FMCG) is one of the fastest growing industries in Egypt. Most Egyptian FMCG manufacturers distribute their products all over the country. Today, the challenge faced by an FMCG supply chain is to establish efficient and successful patterns of distribution to the supply chain members. Because of the rapid increase in FMCG demand, companies are motivated to reconsider the design of their distribution networks. One main result from the increase in demand is the expansion of mass merchandisers which are considered as key customers to FMCG companies. This mandates that the distribution network design should be revised to ensure that the needs and wants of key customers are met through effective and efficient distribution networks. The distribution network design problem involves facility location, warehousing, transportation and inventory decisions. The lot size also affects the problem. This problem is called the integrated lot sizing and distribution problem.

In integrated lot sizing and distribution problems, the companies are concerned with minimising the total cost incurred in distributing the products by determining, for each period in the planning horizon, the quantity produced at each entity, the quantity shipped from each entity and to which customer, the quantity stored at each entity and which types of vehicles are to be used in each link for each period.

The aim of this article is to optimise the integrated lot sizing and vehicle routing problem in the distribution network of one of the leading FMCG companies in Egypt. The company wants to know whether their current practice is efficient or not. The company wants to determine the best distribution plan to adopt to fit its current distribution policy and the distribution plans that fit another three possible alternative distribution policies. Moreover, we want to investigate the effect of the length of the planning horizon and the effect of the collaboration between members on the performance of the distribution plan for the different distribution policies. More specifically, the company wants to find, for each period for a given planning horizon, the production quantity of each member, the stored quantity, the incoming quantity and from which member using which vehicle and the outgoing quantities to which member using which vehicle, with the aim of satisfying the demand at the lowest possible cost.

The rest of the article is structured as follows. In the 'Literature review' section, literature of the relevant research is discussed. In the section 'Problem description and formulation', the problem is described, and a formulation of the problem is introduced. In the section 'Case study', the case study is introduced. In the 'Numerical results' section, the numerical analysis is discussed. Finally, the discussion and recommendation are covered in the 'Conclusion' section.

Literature review

Researchers have long considered the vehicle distribution problem and the lot sizing problem (LSP) as two different well-known classical problems in supply chain management (Adulyasak, Cordeau & Jans 2014). These two problems are closely related to real-life applications where products have to be produced, stored and then distributed to the customers. The decisions are very close, to the extent that optimising them may cause drastic cost-saving to the supply chain members. Kellogg's benefited as much as saving $40 million a year by integrating the production, inventory and distribution decisions (Brown et al. 2001). IBM also saw several improvements in different dimensions (Degbotse et al. 2013). Integrated problems often present advantages from a practical point of view and are becoming the new standard (Adulyasak, Cordeau & Jans 2015; Coelho & Laporte 2013; Coelho & Laporte 2014).

The distribution problem tries to deliver the ordered quantity to the customers with the aim of improving the companies' strategic objectives, which could be reducing price, improving responsiveness or similar objectives. Companies nowadays rely on multichannel distribution networks to achieve different objectives, as surveyed by Simchi-Levi, Kaminsky and Simchi-Levi (2004), Kembro, Norrman and Eriksson (2018) and Melacini et al. (2018). Ghoushchi and Hushyar (2020) proposed a design algorithm for a closed-loop, multistage, multiperiod, multiproduct supply chain network with third-party logistics providers and suppliers using grey theory. Hussein and Kais (2020) discussed the effects of psychographic factors, sociodemographic factors and channel experience factors on the customer's use of a channel search for products versus purchase by customers from the channel. Wallace, Giese and Johnson (2004) indicated that multiple complementary channels can provide a greater and deeper mix of customer service, and therefore enhance the seller's overall value proposition. Recently, the shift towards having direct sales to customers besides the regular distribution network has been studied in the literature (Zhu et al. 2020; Batarfi, Jaber & Zanoni 2016). Taha et al. (2014) consider the effect of the supply disruption.

On the other side, LSP focuses on determining the quantities and timing of production with the objective of production and inventory cost minimisation (El-Beheiry & Abdallah 2019; Karimi, Fatemi Ghomi & Wilson 2003). Memmi and Laaroussi (2013) tried to minimise the sum of startup, setup, inventory and production costs over all periods. Sinha and Anand (2018) discussed the LSP for fast-moving perishable goods. Recently, Mohammadi, Esmaelian and Atighehchian (2020) proposed a mathematical model in which the procurement and production lot-sizing are integrated with scheduling.

It should be noted that the distribution problem and the LSP are both *NP* hard (non-deterministic polynomial-time hard), and thus the solution time increases exponentially with the size of the problem (Florian, Lenstra & Rinnooy Kan 1980; Maes, McClain & Van Wassenhove 1991). Bo et al. (2021) addressed the computational complexity of the problem by solving it using metaheuristics in a reasonable time.

One of the most important drivers in the performance of the integrated lot size and distribution problem is information sharing. When there is no information shared, the supply chain members are considered in a Stackelberg game situation as in Yan et al. (2016) and Maskey, Fei and Nguyen (2020). Vallejos, Matopoulos and Greasley (2020) used simulation of a case study in the United Kingdom (UK) retail sector to show that collaboration across multitier supply chains improves transportation efficiency. Whilst information sharing would improve the surplus of the supply chain, the power position of the main members has a larger effect on the performance. Al-Doori (2019) highlighted the importance of collaboration in improving the performance of automotive industry supply chain. Huang, Guan and Xiao (2018) considered offering a discount for providing important data in a multichannel supply chain. Even with sharing information, the customers may feel afraid that giving too much information may hurt their power position (Prasad et al. 2019). Hoque and Bhattacharya (2020) considered the lot sizing distribution problem for the case of single manufacturer and multiple buyers with a stochastic lead time and deterministic demand with constant rate at the buyers. They proposed a mathematical model formulating the problem and solving it using a heuristic approach. The integrated production and control planning models are studied for different products. Seyedhosseini and Ghoreyshi (2014) considered perishable goods whilst Ghosh and Mondal (2018) considered the dairy industry in India.

This study presents a mixed-integer quadratic problem (MIQP) for the integrated lot sizing and distribution problem for an Egyptian FMCG company. The company has a heterogeneous fleet used in distribution. The company has its own distribution policy and wants to improve it, so another three distribution policies are proposed. There is a possibility for good information sharing between the members. The company selects the length of the planning horizon. For each period in that planning horizon, the company wants to find the quantity to be produced at different production sites, the quantity to be stored at different storing members, the quantity received at each location, the quantity shipped from each location and the type of vehicle used in each incoming or outgoing trip. This is performed with the objective of satisfying the demand at the lowest possible cost.

The novelty of this work is that: (1) it shows the effect of selecting planning horizon on the distribution–production decisions (distribution policies) and how these are sensitive to the selected planning horizon, (2) it gives insights to the decision takers on the performance characteristics of the discussed distribution policies and (3) it evaluates the real-life applicability of choosing a simple distribution policy that is easy to understand and apply by all members versus a more complex distribution policy.

Problem description and formulation

Consider the supply chain of a company that consists of producers, warehouses and retailers. The company produces the products and transports them to the warehouses and retailers. The company has a fleet of different sizes to deliver the products. When a vehicle is utilised, fixed and variable costs are incurred. Also, when there are products stored at a location, a holding cost is incurred. Whilst planning the delivery of products, the company takes into its consideration a long planning horizon (e.g. a planning horizon of an entire year). This time horizon is divided into smaller operational periods (e.g. a monthly delivery period that can be utilised). When a product is delivered in an earlier period than its consumption period, the holding cost would increase.

Whilst planning for the distribution, the company wants to determine how many products to produce at production facilities in each period, how many to ship using which type of vehicles, the route and schedule of each vehicle at different times (i.e. source, destination and load from a location in the supply chain to another at different times within the time horizon) and the product quantity stored at each location across the planning horizon. Whilst taking these decisions, the company tries to satisfy all the demand and wants to minimise the cost. Also, the company wants to study the effect of the length of the planning horizon on the optimal decisions. Moreover, the company wants to know how different distribution policies would affect its decisions (e.g. having the policy of using only large vehicles to deliver to distribution centres and only small vehicles to deliver to the retailers).

The research is based on modelling a real case of an FMCG company to determine the optimal distribution policy and study the effect of the planning horizon on the optimal decisions. The model parameters are deduced from the actual cost values and the trucks' capacities to help the company evaluating the distribution policies. This research is an experimental research as the effect of the planning horizon on the optimal solution is tested.

Consider a supply chain consisting of n entities divided into L echelon as shown in Figure 1. There are T types of trucks available for use, where N^T refers to trucks available for each type, each with a capacity of V^T. When the company plans for a planning horizon of length D, this planning horizon is divided into d smaller delivery periods. If a truck of type t travels from entity i to entity j during delivery period d, the truck incurs a fixed cost $f^T_{i,j,d}$ and a variable cost of $C^T_{i,j,d}$. Each entity that belongs to the last echelon of the supply chain has a demand of $D^d_{i,p}$ for delivery period d and product p. Each entity has a capacity of S_i, whilst each entity belonging to echelon 1 has a production capacity of PQ^p_i. When a product is kept at entity i from a delivery period d to the following delivery period d+1, the entity incurs a holding cost of h_i. Each entity has an initial inventory of iv_i.

The model minimises the total cost incurred in the supply chain, which is divided into transportation and holding costs. This is achieved by determining for every period d the following quantities: (1) the production quantity for each product p produced at entity i at echelon 1 $QQ^P_{i,d}$, (2) the quantity shipped from each source entity i to each destination entity j of a product p using trucks of type t in each delivery period d, denoted as $Q^t_{i,j,p,d}$; and, in addition to the quantities, (3) the type(s) of truck(s) travelling from a source entity to a destination entity in each delivery period, represented by the binary value $X^t_{i,j,d}$.

There are some assumptions in the considered models; without the loss of generality, the product size, variable cost and holding costs are normalised amongst all the products (i.e. all the products have the same size and variable cost). There is no backlog allowed at any entity, and shortage cost is not considered in the model, as in the FMCG's industry the normal operation is to have the highest possible product availability. The truck type used

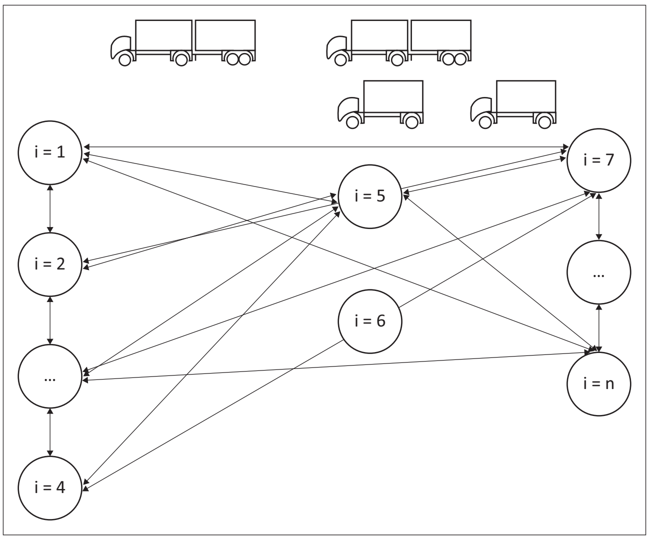

FIGURE 1: General structure of a fast-moving consumer goods supply chain with three echelons.

for shipping from entity i at period d can be changed to any other type at any upcoming period $d+m$ where $m = 1, 2, \ldots. D-d$. Material handling cost is negligible at the distribution centre (DC).

The model uses the following nomenclature:

Parameters:

n	number of entities
L	number of echelons
$t \ldots T$	types of trucks
N^T	number of trucks available
V^T	capacity of trucks of type T
D	length of the planning horizon, divided into d smaller delivery periods
d	number of delivery periods
i,j	entities in the supply chain
p	Product type
$f^T_{i,j,d}$	incurred fixed cost when a truck of type T visits entity j after entity i in delivery period d
$C^T_{i,j,d}$	incurred variable cost when a truck of type T visits entity j after entity i in delivery period d
$D^d_{i,p}$	demand of each entity of the last echelon of the supply chain for delivery period d and product p
S_i	capacity of entity i
PQ^P_i	production capacity of each entity i belonging to echelon 1.
h_i	holding cost when a product is kept at entity i from a delivery period d to the following delivery period $d+1$
IV_i	initial inventory at each entity i

Decision variables:

$QQ^P_{i,d}$	production quantity for each product p produced at entity i at echelon 1
$Q^t_{i,j,p,d}$	quantity shipped from source entity i to destination entity j of a product p using a type of trucks t in each delivery period d
$X^t_{i,j,d}$	binary value representing whether a truck of type t is travelling from entity i to entity j in delivery period d

The associated objective function (1) is divided into two parts: transportation cost and holding (inventory) cost. The transportation cost consists of a fixed cost and a variable cost based on the shipped quantity, the vehicle type and the route. A quantity can only be assigned to a truck if that truck is assigned to travel this link in this delivery period (e.g. for a truck of type 1 to be assigned to visit entity 7 from entity 4 in delivery period 3, the binary decision variable $X^1_{4,7,3}$ is equal to 1, and the cost would be $X^1_{4,7,3}\left(f^1_{4,7,3}+C^1_{4,7,3}\sum_{p=1}^{P}Q^1_{4,7,p,3}\right)$ (see Box 1).

The second term is the holding cost, which can be computed as the holding cost per unit at an entity multiplied by the inventory level. The inventory level for a certain entity at a specific delivery period is computed as the incoming products less the outgoing products. The incoming products include the initial inventory at the beginning, the production quantity for each product at this entity (if it is an entity at echelon 1) and all the incoming products for each delivery period from the first delivery period up through the current period, whilst the outgoing products include all shipped products and all customers' orders from the current entity from the first delivery period up through the current period.

Constraints (2) indicate that the current inventory level at an entity at a specific delivery period is non-negative and cannot exceed this entity's capacity. The only exception is for the final delivery period of the planning horizon, where the remaining inventory level should be zero as shown in constraints 3. Constraints (4) ensure that the sum of all sorts of outgoing quantities is less than what is available at any entity for any single product at any given delivery period, except for the last delivery period where the quantity should all be used as in constraints (5). Constraints (6) limit the produced quantity at any production site for a certain product to its production capacity. Constraints (7) ensure that the sum of all shipped quantity of all products from one entity to another in a given delivery period using a truck of a certain type does not exceed its capacity. Constraints (8) ensure that no more than the available trucks of a certain type can be used in a delivery period. Constraints (9, 10, 11) ensure the non-negativity of the decision variables.

Case study

The case study concerns a multinational FMCG company that distributes its goods throughout 120 distribution centres to its customers, covering all the Egyptian governorates, and these distribution centres are being supplied from the company's eight factories. Two of the factories produce unique products (not produced at any other factories), whilst the other six factories may produce the same products. One of its DCs, located in the Ain Shams suburb of eastern Cairo, will be referred to as Ain Shams Distribution Center (ASDC), which is being supplied by four factories – out of the eight factories owned by the company – located in Alexandria (Alex), Cairo (CAI), 6th of October (OCT) and Qalyoub (Qly). Each factory supplies ASDC with a range of products that is not supplied by any of the other three factories; the quantities supplied will be expressed in number of pallets as each pallet must include the same product. There are two types of truck: trail trucks with a capacity of 30 pallets and common trucks with a capacity of 8 pallets. The company currently uses trailer trucks of capacity 30 pallets to deliver from each factory to ASDC.

ASDC supplies demand points within known territories. This study is concerned with one major territory called El-Oubour city. El-Oubour city has four key customers (KC): *A*, *B*, *C* and *D*. They represent about 70% of the territory's

BOX 1: Formulation of the model.

$$Min\ Z = \sum_{i}^{n}\sum_{j}^{n}\sum_{d=1}^{d}\sum_{t=1}^{T} X_{i,j,d}^{t}\Big(f_{i,j,d}^{t} + C_{i,j,d}^{t}\sum_{p=1}^{P} Q_{i,j,p,d}^{t}\Big) + \sum_{j=1}^{n} h_j\Big[\sum_{dd=1}^{d}\Big(\sum_{p=1}^{P}\big(IV_j^p\big) + \Big(\sum_{d=1}^{dd}\Big(\sum_{t=1}^{T}\sum_{i=1,i\neq j}^{n}\sum_{p=1}^{p} X_{i,j,d}^{t}\,Q_{i,j,p,d}^{t} - \sum_{t=1}^{T}\sum_{k=1,k\neq j}^{n}\sum_{p=1}^{p} X_{j,k,d}^{t}\,Q_{j,k,p,d}^{t} + \sum_{p=1}^{p}\big(QQ_{j,d}^{p} - D_{j,p}^{d}\big)\Big)\Big)\Big)\Big] \quad (1)$$

subject to:

$$0 \leq \sum_{dd=1}^{d'}\Big(\sum_{p=1}^{P}\big(IV_j^p\big) + \Big(\sum_{d=1}^{dd}\Big(\sum_{t=1}^{T}\sum_{i=1,i\neq j}^{n}\sum_{p=1}^{P} X_{i,j,d}^{t}\,Q_{i,j,p,d}^{t} - \sum_{t=1}^{T}\sum_{k=1,k\neq j}^{n}\sum_{p=1}^{P} X_{j,k,d}^{t}\,Q_{j,k,p,d}^{t} + \sum_{p=1}^{P}\big(QQ_{j,d}^{p} - D_{j,p}^{d}\big)\Big)\Big)\Big) \leq S_j\ \forall j \leq n; \forall d' \leq d-1 \quad (2)$$

$$\sum_{dd=1}^{d'}\Big(\sum_{p=1}^{P}\big(IV_j^p\big) + \Big(\sum_{d=1}^{dd}\Big(\sum_{t=1}^{T-1}\sum_{i=1,i\neq j}^{n}\sum_{p=1}^{P} X_{i,j,d}^{t}\,Q_{i,j,p,d}^{t} - \sum_{t=1}^{T}\sum_{k=1,k\neq j}^{n}\sum_{p=1}^{P} X_{j,k,d}^{t}Q_{j,k,p,d}^{t} + \sum_{p=1}^{P}\big(QQ_{j,d}^{p} - D_{j,p}^{d}\big)\Big)\Big)\Big) = 0 \quad \forall j \leq n; \forall d' = d \quad (3)$$

$$\sum_{dd=1}^{d'}\Big(\big(IV_j^p\big) + \Big(\sum_{d=1}^{dd}\Big(\sum_{t=1}^{T}\sum_{i=1,i\neq j}^{n} X_{i,j,d}^{t}\,Q_{i,j,p,d}^{t} - \sum_{t=1}^{T}\sum_{k=1,k\neq j}^{n} X_{j,k,d}^{t}Q_{j,k,p,d}^{t} + QQ_{j}^{p} - D_{j,p}^{d}\Big)\Big)\Big) \geq 0\ \forall j \leq n; \forall d' \leq d-1; p \leq P \quad (4)$$

$$\sum_{dd=1}^{d}\Big(\big(IV_j^p\big) + \Big(\sum_{d=1}^{dd}\Big(\sum_{t=1}^{T}\sum_{i=1,i\neq j}^{n} X_{i,j,d}^{t}\,Q_{i,j,p,d}^{t} - \sum_{t=1}^{T}\sum_{k=1,k\neq j}^{n} X_{j,k,d}^{t}Q_{j,k,p,d}^{t} + QQ_{j,d}^{p} - D_{j,p}^{d}\Big)\Big)\Big) = 0\ \ \forall j \leq n; p \leq P \quad (5)$$

$$0 \leq QQ_{j,d'}^{p} \leq PQ_j^p\ \ \forall j \leq n; p \leq P; d' \leq d \quad (6)$$

$$\sum_{p=1}^{p} Q_{i,j,p,d'}^{t} \leq V^t X_{i,j,d'}^{t}\ \ \forall i, j \leq n; i \neq j; d' \leq d, t \leq T \quad (7)$$

$$\sum_{i}^{n}\sum_{j;j\neq i}^{n} X_{i,j,d}^{t} \leq N^t\ \forall d' \leq d; t \leq T \quad (8)$$

$$Q_{j,k,p,d'}^{t} \geq 0\ \forall i, j \leq n; i \neq j; d' \leq d; p \leq P; t \leq T \quad (9)$$

$$X_{i,j,d'}^{t} \text{ are binary } \forall i, j \leq n; i \neq j; d' \leq d; t \leq T \quad (10)$$

$$QQ_{t,d'}^{P} \geq 0\ \forall i \leq n; d' \leq d; p \leq P \quad (11)$$

demand. The current distribution network design to these KCs is shown in Figure 2. These four KCs can be divided into two groups according to their demand, represented by the number of pallets needed from each product. The first one includes customer '*A*', whilst the second one includes the remaining three, with the first group denoted as key customer 1 (KC1) and the second group as KC2. The two groups have an equal demand, which is a fully loaded truck of a common truck type with a capacity of eight pallets. The product mix is agreed upon with the KCs and must follow the percentages given in Table 1. The shipping frequency to the KCs is one shipment every 2 days divided evenly between the two groups. The transportation costs for both types of trucks (trailer and common) between the factories to ASDC and the KCs are given in Tables 2 and 3. The transportation between the KCs at the second group is negligible and therefore it will not be considered, and no lost sales or backlogs are allowed.

The company wants to have a fixed distribution policy known for all the stakeholders so that they can better optimise their operations. Therefore, the company wants to investigate four different distribution policies, where each one represents a different distribution policy with different levels of coordination with the KCs. In each distribution policy, the quantities to be produced, shipped and stored must be optimised in addition to the type of trucks utilised. For each distribution policy, the company wants to investigate the effect of the planning horizon on the decisions taken

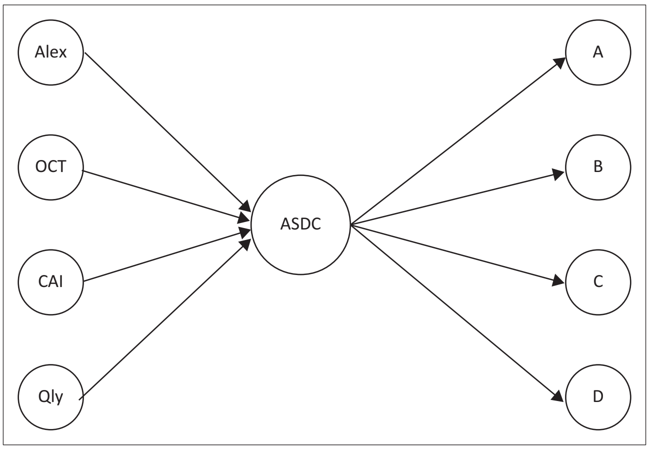

FIGURE 2: Current distribution network design for El-Obour city.

TABLE 1: Product mix demand of the key customers.

Factory	Alex	CAI	OCT	Qly
Demand (%)	10	50	5	35

Alex, Alexandria; CAI, Cairo; OCT, 6th of October; Qly, Qalyoub.

TABLE 2: Transportation cost matrix for trailer trucks.

To From	Alex	OCT	CAI	Qly	DC	KC1	KC2
Alex		950	1100	1060	1060	1300	1300
OCT	950		650	780	670	700	700
CAI	1100	650		720	650	470	470
Qly	1060	780	720		720	680	680
DC	1060	670	650	720		710	710
KC1	1300	700	470	680	710		50
KC2	1300	700	470	680	710	50	

Alex, Alexandria; CAI, Cairo; OCT, 6th of October; Qly, Qalyoub; DC, distribution centres; KC1, key customer 1; KC2, key customer 2.

TABLE 3: Transportation cost matrix for common trucks.

To From	Alex	OCT	CAI	Qly	DC	KC1	KC2
Alex		450	500	480	480	550	550
OCT	450		350	400	370	360	360
CAI	500	350		370	350	340	340
Qly	480	400	370		370	350	350
DC	480	370	350	370		360	360
KC1	550	360	340	350	360		5
KC2	550	360	340	350	360	5	

Alex, Alexandria; CAI, Cairo; OCT, 6th of October; Qly, Qalyoub; DC, distribution centres; KC1, key customer 1; KC2, key customer 2.

and the total cost. Thus, for each distribution policy, the planning horizon will be changed starting from one period to six planning periods.

Distribution policy 1: Current distribution network design

The current practice of the distribution network is to ship trailer trucks to the ASDC, which works as a cross dock, and then ship aggregated orders to the KCs, as given in Figure 3a. Shipping takes place each single period and the planning horizon stays one single period and no storage takes place, neither at the DC nor at any customer. Trailer trucks are used between factories and the DC while common trucks are used between the DC and the KCs.

Distribution policy 2: Direct shipping to key customers

In this case, shown in Figure 3b, shipping takes place as direct shipping from the factories to the KCs without passing by the DC. In this case, the common trucks are not used.

Distribution policy 3: Mixed distribution network design

In this case, all trucks are allowed to travel from any location to any other location, incurring the associated costs. The shipping may be done directly from the factories to KCs or through ASDC, as shown in Figure 3c.

Distribution policy 4: Vendor managed inventory

The company manages the inventory of the KCs, and they share information with the factories. This distribution policy is similar to the third one, yet the company may choose to pay some of the holding costs at the KCs, and in return, it may not need to ship every other day to them, as shown in Figure 3d.

Numerical results

The developed model is tested on the FMCG company under study. The model is an MIQP that can be solved to optimality for up to intermediate planning horizons.

The quadratic model developed was solved using Lingo. The results are shown in Tables 4 and 5 for different planning periods for the total cost and the cost per delivery period, respectively.

For distribution policies 1, 2 and 3, some arcs are not allowed for certain types of trucks (e.g. common trucks between factories and DC in distribution policy 1 and arcs reaching the DC in distribution policy 2). The fixed transportation cost is set to an arbitrary large number, prohibiting the model from selecting these arcs. Whenever the inventory is prohibited at any entity, the holding cost is also set to a high value likewise.

It is observed that with distribution policies 1, 2 and 3, the cost per delivery period is the same across all the different planning periods, as shown in Figures 4 and 5. In that sense, the different planning periods are treated as a repeat of a one-period plan.

It could be concluded from Figure 4 that if the company has to choose from distribution policies 1, 2 and 3, which are straightforward for the company to implement, then distribution policy 1 would be the worst choice. Comparing distribution policies 2 and 3, distribution policy 2 is slightly more expensive than distribution policy 3. Distribution policy 2 has the benefit of eliminating the DC altogether, decreasing the effort in handling the material. Distribution policy 3 is cheaper than distribution policies 1 and 2 because of the flexibility of using any truck in a way to minimise the cost. However, the cost savings of distribution policy 2 over distribution policy 3 should be qualitatively evaluated against the added effort resulting from the freedom of choosing any truck and the added operations at the DC.

Figure 4 also shows that distribution policy 4 is consistently cheaper than the other three cases. This could be attributed to several factors: (1) the economies of scale in utilising more products in the vehicles, (2) the holding cost is relatively cheaper and (3) the difference in the cost per unit of operating a trailer truck when it has a high utilisation is significantly cheaper.

Figure 5 shows the constant cost per period, as discussed before for distribution policies 1, 2 and 3. Further investigation of distribution policy 4 showed three interesting patterns of cost reductions. The first is when the planning horizon is

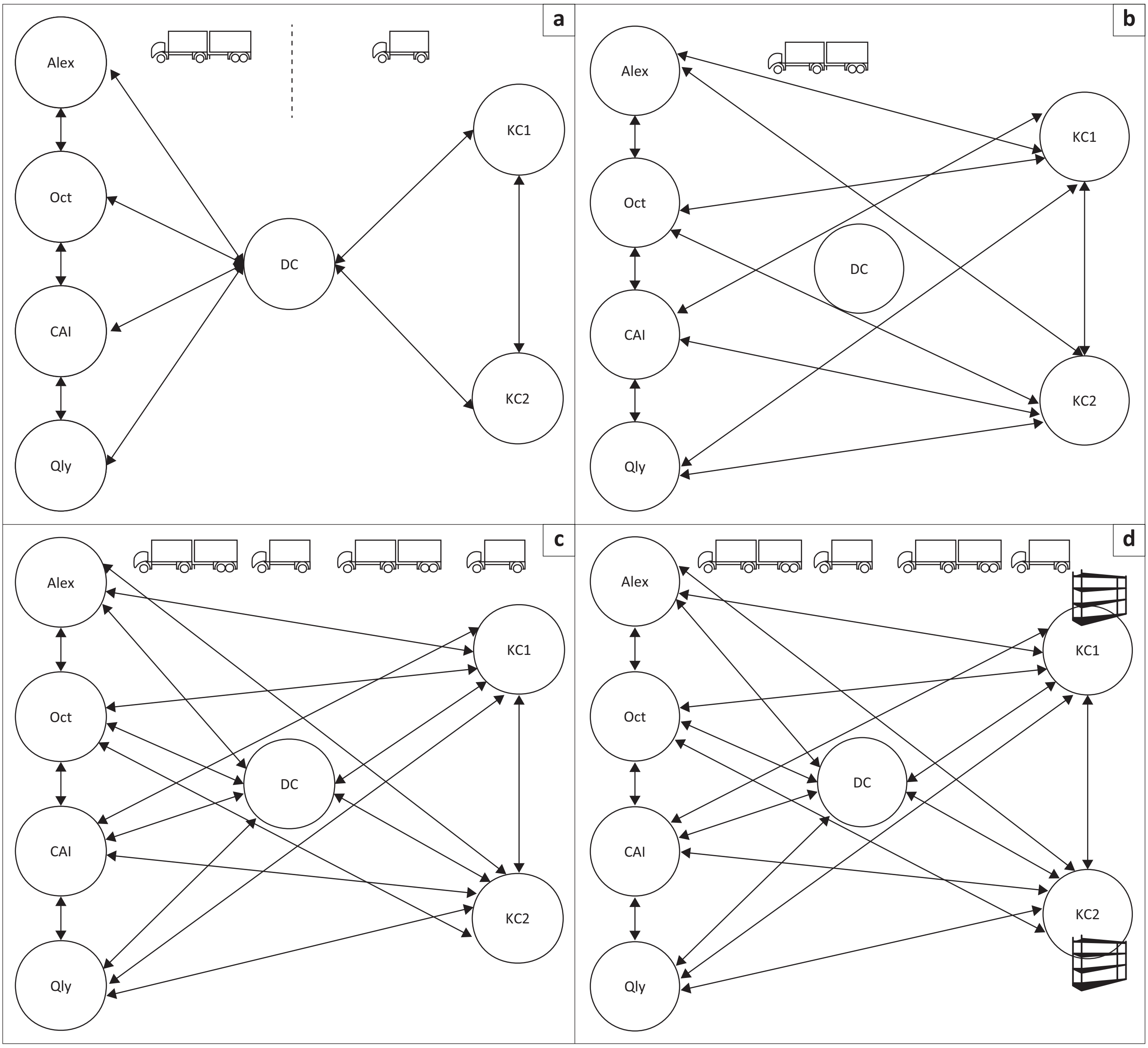

FIGURE 3: The four distribution policies of the considered distribution network designs.

TABLE 4: The total cost resulted from the mixed integer quadratic problem for different planning periods.

Planning period	Distribution policy 1	Distribution policy 2	Distribution policy 3	Distribution policy 4
1	1885	1605	1500	1500
2	3770	3210	3000	1517.8
3	5655	4815	4500	2148.4
4	7540	6420	6000	2186.8
5	9425	8025	7500	2303
6	11 310	9630	9000	2666.62

slightly increased from a low value (e.g. from one period to two periods), the reduction of the cost per period here is attributed to the better utilisation of the small vehicles, especially when the fixed cost is significantly high and distributed over small periods. The second cost reduction pattern is when the planning horizon is increased to a moderate planning horizon (e.g. from a planning horizon of two periods to a planning horizon of three periods).

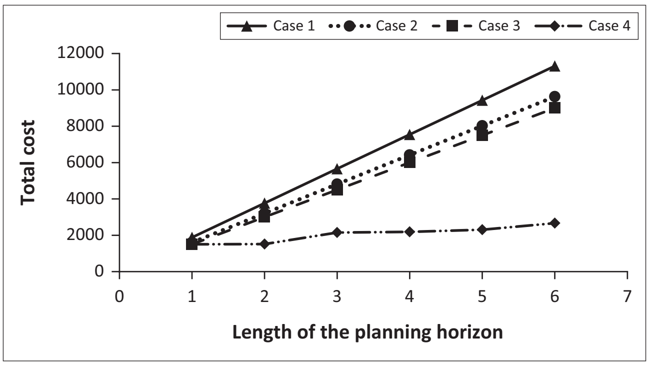

FIGURE 4: Total cost versus planning period.

The reduction in the cost per period is not as large as the previous one. This can be attributed to the fact that the previous truck types used in the previous planning periods were already moderately utilised. Therefore, increasing the

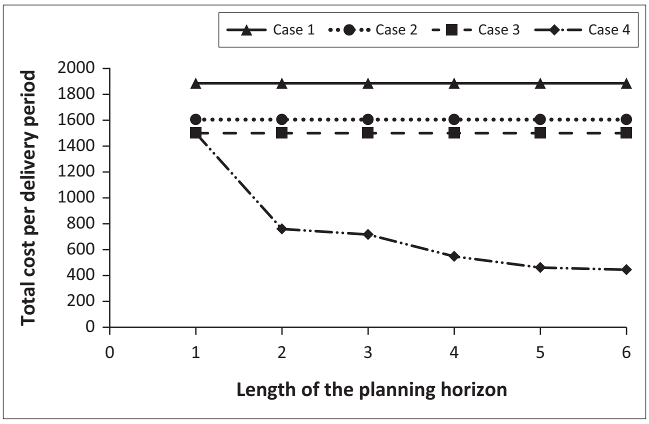

FIGURE 5: Cost per delivery period versus planning period.

TABLE 5: The total cost per period resulted from the mixed-integer quadratic problem for different planning periods.

Planning period	Distribution policy 1	Distribution policy 2	Distribution policy 3	Distribution policy 4
1	1885	1605	1500	1500
2	1885	1605	1500	758.9
3	1885	1605	1500	716.1333
4	1885	1605	1500	546.7
5	1885	1605	1500	460.6
6	1885	1605	1500	444.4367

planning horizon leads to better utilising the same type of vehicles but at the expense of an increase in the holding costs. Hence, the reduction rate is smaller. The third cost reduction pattern is for the large planning horizons (e.g. increasing the planning horizon from three periods to four planning periods). Once again it shows a good reduction in the cost per period. This can be attributed to the change of the types of trucks from the small trucks to the large trucks, taking advantage of the economies of scale. It should be noted that when the planning horizon further increases from five to six delivery periods, the savings resulted from the utilisation of the large trucks diminish as the incurred holding costs increase.

From the above analysis, the results suggest that there is a trade-off between the ease of the distribution policy and the cost of execution of the distribution plan. The cost of executing a simple distribution policy could be improved a bit by adequate planning. On the other hand, a complex distribution plan could improve the cost significantly, but will face challenges by being complex. Moreover, it is found that the planning horizon affects the cost of the execution of the operation policy. Choosing a small planning horizon could lead to missing the opportunity of aggregating several demands in one shipment. But using a large planning horizon diminishes the savings and may prove to be more expensive.

Conclusion

In this article, a mixed-integer quadratic model is introduced to solve the integrated lot-sizing and vehicle routing problem applied to an international well-known FMCG company in Egypt. The company faces a trade-off between choosing a simple fixed policy that is easy to implement and easy to understand by all stakeholders or a sophisticated plan that involves more complicated planning from involved planners from all stakeholders. In addition to the simple distribution policy adopted by the company, two more simple distribution policies and another complex distribution policy are proposed.

This study finds that if the company chooses a simple fixed distribution policy, then distribution policy 3 with the flexibility of using any type of trucks available and shipping the exact demand for one planning period would be the cheapest choice. However, distribution policy 2 is not significantly more expensive and eliminates the DC along with its handling cost and the managerial effort in managing it.

If the company wants to further reduce its cost significantly, then the option of adopting VMI in distribution policy whilst paying some of the KCs' holding costs would be a better choice. However, the company has to evaluate the trade-off between reducing the costs and increasing the effort required to manage all the activities associated with the distribution. This is especially valid as there are three patterns of cost reductions that appear in the case study. It is clear from the numerical results that better utilisation of a small vehicle or higher utilisation of a bigger vehicle is better than just switching from a highly utilised small truck to a bigger under-utilised vehicle.

The results prove that an important factor to consider in the problem is the number of planning periods considered in the planning horizon. Changing the number of planning periods affects the optimal decisions, as in the fourth distribution policy, and helps reduce the total costs. In the beginning of increasing the planning horizon, small vehicles start to be loaded by more products, increasing the utilisation and reducing the cost per period. In a moderate planning horizon, the vehicle becomes moderately utilised and the improvement by the increased utilisation is decreased by the holding cost. When the planning horizon is further increased, larger vehicles are needed, leading to improvement in the utilisation and hence improving the cost per delivery period. However, when the planning horizon becomes large, the holding cost reduces the gains.

This combinatorial problem is *NP* hard and requires a long solution time for a long time horizon. Possible future research for this work is to develop a metaheuristic solution to solve larger-scale problems.

Acknowledgements

Competing interests

The authors have declared that no competing interest exists.

Authors' contributions

Both authors contributed equally to the writing this article.

Ethical considerations

This article followed all ethical standards for a research without direct contact with human or animal subjects.

Funding information

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Data availability

Data are available upon reasonable request to the corresponding author.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

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