Optimization of the Supply Chain System of a Food Factory

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Abstract

Linear Programming models were developed for the supply chain system of a food factory to determine the best locations, capacity extensions, and optimum distribution schedules with alternative modes of transportation. The results of the model showed that using classical linear programming optimization procedures for a supply chain and capacity extension problem can significantly reduce operational costs and help managers make correct decisions for the optimum performance of their systems

Keywords
Supply Chain, Linear Programming, Distribution Center, Optimization, Location

1. Introduction
Supply chain management deals with the flow of goods, the type and amount of production, and storage at each process stage. It also deals with selecting the location of the production and storage facilities and sharing information at different levels of the network. Manufacturing companies and distributing organizations try to make their supply chain more efficient to achieve specific objectives. A supply chain shows the big picture of any system and affects its operational conditions. Facility location, such as a manufacturing facility or a storage facility, is a significant problem faced in supply chain management. Location decisions have significant effects on transportation, inventory, and operational costs. It is necessary to analyze the system and construct a mathematical or a simulation model.

This paper considers a canned food company, which manufactures canned food in Kuwait and distributes it to various countries in the Middle East, North Africa, and the U.S.A. The company cannot keep up with the demand and wants to establish a new manufacturing facility. The company system was analyzed, and a simulation model was used to determine an optimum location for this new manufacturing facility.

2. Literature Review
Many research papers have been published on facility location in a supply chain system. Revelle and Laporte (1996) discussed new models and research prospects for the plant location problem, which is indicated to have a significant effect on the performance of the system and the organization in general. Carod and Maria (2005) presented a case study for industrial location and related determinants. Heizer and Render (2006) indicated that supply chain management is highly influenced by site selection for a facility location. Baron et al. (2011) presented a robust optimization procedure for the facility location problem. Chen et al. (2014) discussed the manufacturing facility location problem for the sustainability issue and presented a literature review and research agenda on this subject.

Benalcazar et al. (2017), Eroglu and Keskinturk (2005), Kocakaya (2013), and Lee (1993) have used various optimization models and algorithms to solve warehouse location problems.

Alberto (2000) indicated that a warehouse should be situated in a location that would increase the supply chain's overall efficiency and reduce delays in the shipment process. Demirel et al. (2010) indicated that delivering goods to and from the warehouse raises the demand for a proper transportation system, such as road networks, seaports, airports, and railway stations. Warehouse location is a strategic decision. Nekutova et al. (2015) studied the warehouse location problem as a strategical and operative logistic decision and discussed the related issues. Bairagi et al. (2013) have used a hybrid fuzzy technique to select warehouse locations in a supply chain under a utopian environment. KrSingh et al. (2018) presented a case study related to a warehouse location selection of a global supply chain system. Szczepański et al. (2019) used a simulation analysis approach for warehouse location problems in designing a supply chain system.

3. Methods

A linear programming model is constructed to determine the optimum location and the optimum distribution schedule for the company. The model was solved, and optimum results were obtained, which significantly reduced costs. The models and the results are presented with the collected data in the following sections.

4. Data Collection and Problem Analysis

A supply chain consists of all parties involved directly or indirectly in fulfilling a customer request. It is a dynamic system and involves a constant flow of information, product, and funds between different parties at different stages. The value a supply chain generates is the difference between what the final product is worth to the customer and the supply chain's effort to fill the customer's request. The canned food production system's supply chain can be classified as a pull system when it comes to meeting demand from its overseas and Gulf region customers; it orders its raw materials from its suppliers and manufactures canned food to meet the required demand. For its local customers, based on historical demand from coopefigratives, wholesalers, and small stores, the company keeps an inventory to satisfy the demand. The company uses two modes of transportation to fulfill its customer's orders: truckloads for transportation by land and ship containers by the sea with a capacity of 2100 and 1650 cartons, respectively. Figure 1 shows the supply chain stages, and Figure 2 shows the operation of a typical supply chain system.

Figure 1. Supply chain stages.

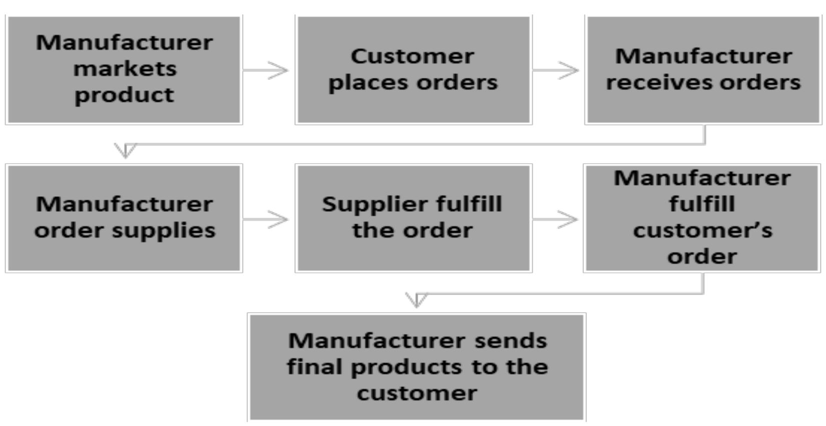

Figure 2. A typical supply chain system.

Customer Order Cycle occurs at the customer/distributor interface and includes all processes directly involved in receiving and filling a customer's order: customer arrival, customer order placement, fulfillment of the order, and order received. Manufacturing Cycle occurs at the distributor/ manufacturer interface. It is related to production scheduling and includes all processes involved in replenishing inventory triggered by customer orders, replenishment orders, and forecasting customer demand. Procurement Cycle occurs at the manufacturer/supplier interface and includes all processes necessary to ensure that materials are available for all manufacturing to occur according to the schedule. Supply chain cycles are illustrated in Figure 3.

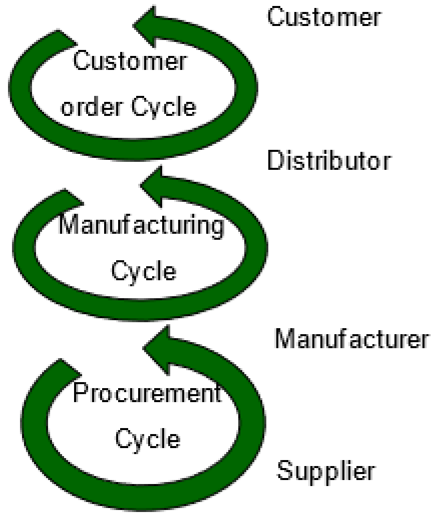

Figure 3 supply chain cycles.

Cycles are handy when considering operational decisions because they specify the roles and responsibilities of each member of the chain. The push/pull view is beneficial when considering the strategic decisions relating to supply chain design.

4.1 Warehouse Locations

Two warehouses belong to the Canned Food Production Co. One is located in Sabhan area in Kuwait and is used to store final products and only the material/equipment needed for near production. The other warehouse is in Kabd area in Kuwait and is used for storing the packing material until it is needed. The locations of the warehouses are shown on the Kuwait map in Figure 4.

Figure 4 Company warehouse locations on Kuwait map.

4.2 Distribution Network

The canned food company distributes its final products, by land, to a local distributor who is then in charge of delivering the products to the cooperatives and wholesalers and minor stores in Kuwait, to six Gulf Countries, to two countries in Africa and Houston, TX, in the U.S.A. by ships. The imported packing and raw materials arrive at Shuwaikh Port in Kuwait. The packing material is then transported to Kabd and the raw materials to Sabhan. When the packing material is needed, it is then sent to Sabhan. The company manufactures for other Gulf countries and overseas customers based on customer requests but does keep inventory for its local customers. Figure 5 shows the distribution of the products to different countries from Kuwait. Figure 6 illustrates the supply chain network for the company.

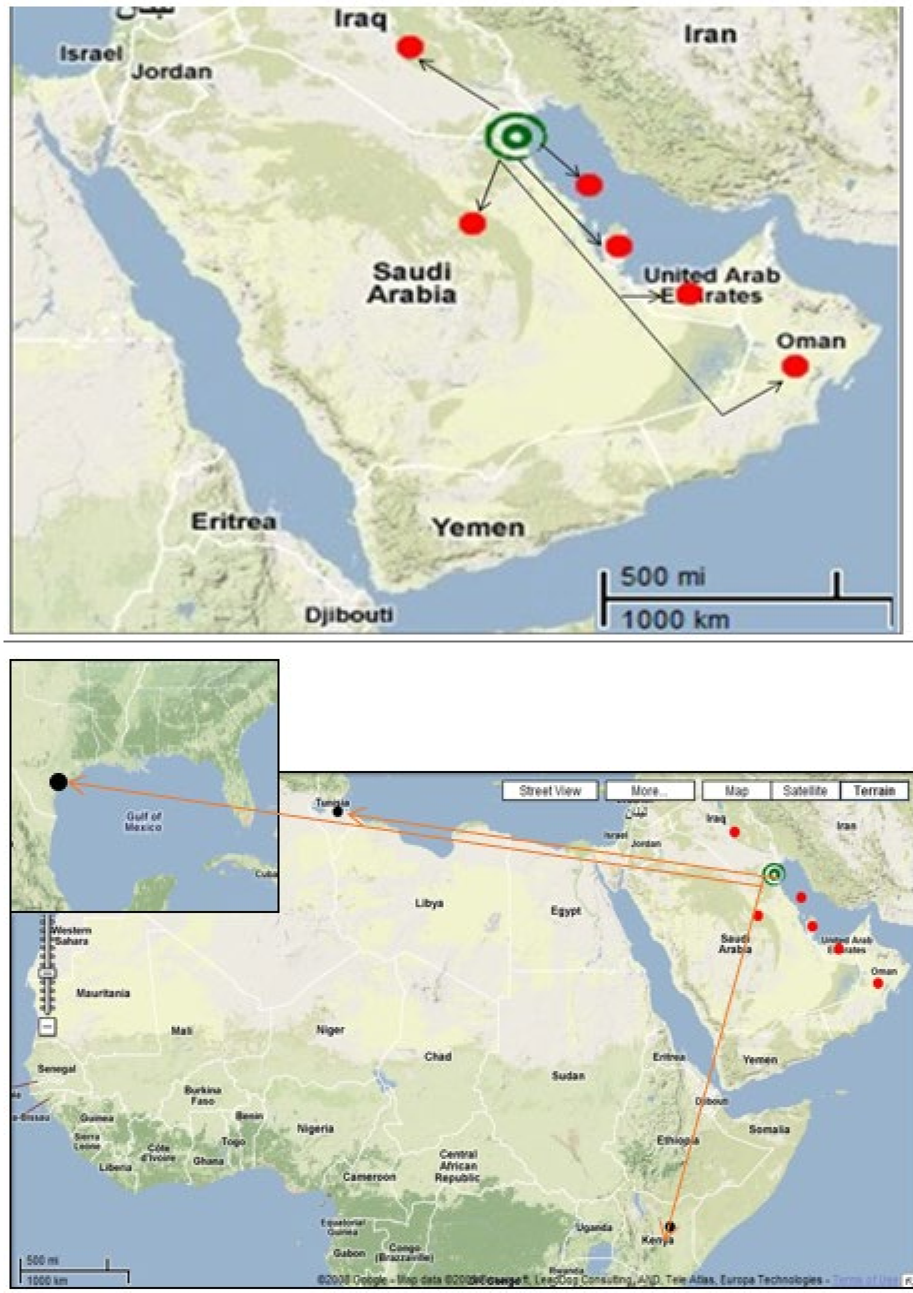

Figure 5. Food Products Customers in the Gulf Region, Africa and Overseas.

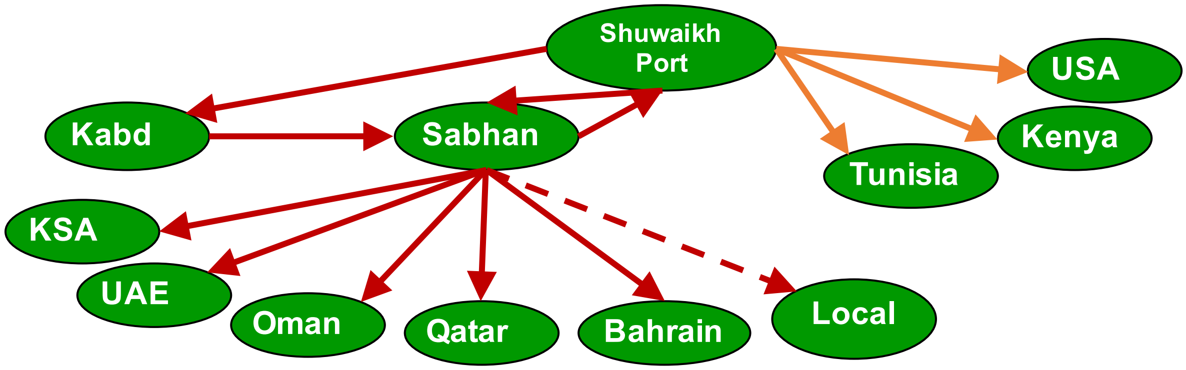

Figure 6 Supply-chain network

4.3 Current Average Demand and Costs

Based on historical data, current demand, the capacity of the transporter, and costs are obtained and presented in Table 1. Note that every truck (sometimes called trailer) has a capacity of 2100 cartons (every carton holds 24 cans), and every container (used for shipping modes) has a capacity of 1650 cartons**.**

Table 1. Average demand and transportations costs for all customers

	Average Demand (Transporter/Month)	Capacity of Transporter (Cartons)	Cost (KD/Transporter)	Total Cost (KD/Month)
Local	28	2100	0	0
KSA	6	2100	200	1200
UAE	5	2100	300	1500
Bahrain	4	2100	290	1160
Qatar	3	2100	300	900
Oman	3	2100	400	1200
Iraq	3	2100	150	450
Tunisia	2	1650	815	1630
USA	3	1650	980	2940
Kenya	3	1650	1300	3900
Totals	122400 cartons/month			**14880**

4.4 Problem Statement

The canned food company has to keep the production line running over time due to the great demand for its products. The company is incapable of satisfying demand with its official scheduled working hours. The company produces 4,000 cartons daily on average (without considering overtime hours), equal to 104,000 cartons per month. The total monthly demand on average is equal to 122,400 cartons. The factory must produce almost 15% of the demand during overtime. Overtime hours do not come free of charge, however. It costs the company, on average, 1,750 KD per month (an amount of about 70,000 dollars per year), which is considered an extra, unnecessary expense for the company, and it is a work overload on the workers at the company. The system is thereby expensive not operating at optimum.

4.5 Model Development and Alternative Solution Approaches

After studying the company's current supply chain, a linear programming model was constructed for three cases and used to study the profitability of each case. Table 2 shows the demand for the products, transportation costs, and the monthly capacities of the existing facilities, where K.S.A refers to the Kingdom of Saudi Arabia, and U.A.E refers to the United Arab Emirates.

Table 2. Data related to demand and transportation.

Demand City (j) Transportation Cost (C_{ij}) per 2100 cartons (K.D.)								***Monthly Capacity (x2100 cartons) (K_i)***
(i)	Kuwait (1)	K.S.A. (2)	U.A.E. (3)	Bahrain (4)	Qatar (5)	Oman (6)	Iraq (7)	
Kuwait - Existing (1)	0	200	300	290	300	400	150	***42***
Kuwait - Potential (2)	0	200	300	290	300	400	150	***90***
K.S.A. - Potential (3)	200	0	100	90	100	200	350	***90***
Monthly Demand (D_j) (x2100 cartons)	***28***	***6***	***5***	***4***	***3***	***3***	***3***	***Total Demand 54***

Three cases for which models are constructed are listed below:

1. Opening a new factory in 2 potential sites (in Dammam-Kingdom-Saudi Arabia (K.S.A.) and Kuwait).
2. Using a new mode of transportation
3. Increasing the capacity of the existing factory by replacing the bottleneck machines.

This study aims to analyze the system with the proposed models above to raise the company's awareness of the necessity of increasing its production capacity and look further into related problems. The following assumptions were made in developing the models:

1. Establishment and fixed costs for the two alternatives are the same.
2. Any regulations regarding establishing a new factory in K.S.A. were overlooked.
3. Costs of transportation from K.S.A. are estimated using the obtained data for transportation from/in Kuwait.
4. Sabhan (Kuwait) will remain to produce for the overseas markets and therefore will not be included in the modeling.
5. The average monthly capacity is 50 truckloads. Since the overseas markets will not be considered, their demand will be deducted from the total monthly capacity. Therefore, the monthly capacity will be 42 units.

5. Modeling and Analysis of Results

5.1 Alternative Case 1: Establishing a New Factory

The potential sites for establishing a new factory are Kuwait and KSA-Dammam. Dammam is considered one of the most industrial cities in K.S.A. It is an easily accessible city. Also, the distributor is located in Dammam, so the cost estimates are valid. Annual operating and maintenance costs, including the equivalent of initial establishment costs, are 6458 KD for the factory, which exists in Kuwait; 5323 KD for the proposed factory to be established in Kuwait, and 5323 KD for the proposed factory to be established in K.S.A. These costs were estimated based on discounted initial costs for a fixed life cycle of 10 years and the annual operating and maintenance costs.

Linear Programming Model 1:

Input Variables:

C_{ij} : Cost of transporting one truck from i to j.
D_j : Demand of j.
K_i : Capacity of i.
A_i : Annual equivalent of running/establishing factory.

Decision Variables:

Y_{ij} : Whether j is covered by i or not.
S_i : Whether a factory exists or is established at i or not.

Objective Function:

$$\text{Min. } Z = \sum_{\substack{1\le i\le 3\\ 1<j<7}} CijDjYij + \sum_{\substack{1\le i\le 3\\ 1<j<7}} AiSi$$

Constraints:

$\sum_{i=1}^{3} Y_{ij} = 1$ j = 1, 2, … ,7

Ensures that the demand of every market is supplied by one factory.

$Y_{ij} \le S_i$ i = 1, 2, 3 and j = 1, 2, … ,7

Ensures that a factory can only cover a market's demand if it exists or is established.

$\sum_{j=1}^{7} D_i\ Y_{ij} \le\ K_i S_i$ i = 1, 2, 3

Ensures that the demand supplied by a factory does not exceed its capacity.

$\sum_{i=2}^{3} Si = 1$

Ensures that only one new factory is opened in either K.S.A. or Kuwait.

$S_1 = 1$

Ensures that Kuwait Plant Exists.

$Y_{ij} = \{0,1\}$

Whether a market i is supplied by a factory j or not.

$S_i = \{0,1\}$ i = 2,3 whether a factory is established at K.S.A. or Kuwait

Output Results of the Model 1 Solution:

LİNDO solved the L.P. model, and the results showed that a new factory should be established in K.S.A. with the truck/load transport distribution plan, as shown in Table 3. The total cost of such a plan was 13,991 KD/month.

Table 3. Model 1 output.

D_jY_{ij}	Kuwait	KSA	UAE	Bahrain	Qatar	Oman	Iraq	Total Truck loads
Kuwait	28	0	0	0	0	0	3	31
KSA	0	6	5	4	3	3	0	21
								Total Cost = 13991 KD/month

S2 = 0
S3 = 1

5.2 Alternative Case 2: Using New Trucks for Transportation

K.G.L. Co. sends trucks with a capacity of 67.7 m^3 to two existing customers. Thus, the capacity of the new truck is 4130 cartons. We will study if using these trucks as a mode of transportation from Kuwait to K.S.A.-Dammam and the U.A.E. will help reduce transportation costs compared to establishing a new factory. The related cost information is summarized in Table 4.

Table 4. Price quotation from K.G.L.

	K.S.A. - Dammam	U.A.E.
Cost from Kuwait (KD/truck)	300	450
Average Demand (truck/month)	3	3

Linear Programming Model 2:

Input Variables:

Cij : Cost of transporting one truck from i to j.
Dj : Demand of j.
Ki : Capacity of i.

Decision Variables:

Yij : Whether j is covered by i or not.
Si : Whether a factory exists or is established at i or not.
Tij : Whether the new trucks are used to transport from i to j.

Objective Function:

$$\text{Min} \sum_{\substack{1\le i \le 3\\ 1<j<7}} CijDjYij + \sum_{i=1}^{3} AiSi + \sum_{\substack{1\le i \le 3\\ 1<j<7}} CijDjTij$$

Constraints:

$\sum_{i=1}^{3} Yij + Tij = 1$ j = 2, 3

Ensures that the demand of every market is supplied by one factory using one mode of transportation.

$\sum_{i=1}^{3} Yij = 1$ j = 1, 4, 5, 6, 7

Ensures that the demand of every market is supplied by one factory.

Yij ≤ Si i = 1, 2, 3 and j = 1, 2, … , 7

Ensures that a factory can only cover a market's demand if it exists or is established.

$\sum_{j=1}^{7} DjYij + DjTij \le KiSi$ i = 1, 2, 3

Ensures that the demand supplied by a factory by one mode of transportation does not exceed its capacity.

$\sum_{i=2}^{3} Si = 1$

Ensures that only one new factory is opened at either K.S.A. or Kuwait.

S1 = 1

Ensures that Kuwait Plant Exists.

Yij = {0,1}

Whether a market i is supplied by a factory j or not.

Si = {0,1} i = 2,3

Whether a factory is established at KSA or Kuwait

Output Results of Model 2 Solution:
Results showed that the best option is establishing a new factory in K.S.A. again. Distribution results are shown in Table 5.

Table 5. Model 2 output results.

D_jY_{ij}	Kuwait	KSA	UAE	Bahrain	Qatar	Oman	Iraq	Total Truck loads
Kuwait	28	0	0	0	0	0	3	31
KSA	0	6	5	4	3	3	0	21
								Total Cost = 13991 KD/month

$S_2 = 0$; $S_3 = 1$; $T_{12} = 0$; $T_{13} = 0$

In order to compare and justify the two alternatives above, discounted cost values are used. Table 6 shows the annual cost values for the new factory. Considering ten years for the system life cycle, the discounted present value (P.W.) of the costs is calculated using an interest rate of 12%. PW= 2,389,322 KD.

Table 6. Annual costs for system operation

Cost Type	Annual Cost (K.D./Year)
Overtime costs	21,000
Maintenance costs	77,500
Operation costs	178,560
Transportation costs	145,812

Case 1. Current (Kuwait) Factory in New Situation:
Maintenance costs remain the same (77,500 KD/year) because the machines are untouched. The transportation costs include only the costs involved in the new distribution plan and amount to 107,040 KD/year. The operation costs are equal to 65% of the current operation costs (amounting to 94,778 KD/year) because the current factory will produce only 65% of its current production in the new situation. Again, the net present worth (P.W.) is calculated based on a 10-years project life and a 12% interest rate. The net present worth was PW= 1,578,209 KD

Case 2. New Factory
For the case of a new factory, no corrective maintenance should be applied in normal conditions. However, the preventive maintenance will be carried out on the same schedule as the current factory, which will result in constant

costs. The new factory will be shipping to K.S.A, Bahrain, U.A.E, Qatar, and Oman. These locations demand 35% of the current production, and operation costs are calculated based on this. Maintenance costs amount to 10,800 KD/year; transportation costs amount to 21,120 KD/year, and operation costs amount to 51,035 KD/year. There is also an initial cost of 300,000 KD at time zero. The net present worth (P.W.) for a 10-years project life and 12% interest rate would be PW=768,715 KD. Total present worth for the company is obtained by summing the P.W. for the current factory in the new situation and that of the new factory, which resulted in PW=1,578,209 + 768,715 = 2,346,924 KD. This resulted in a savings of: Total Cost Savings = ((2,389,322 - 2,346,924)/ 2,389,322) x 100=1.77 %

5.3 Alternative Case 3-Increasing Capacity of Existing Factory*:*

The capacity of the existing factory in Kuwait could be increased if the bottleneck machines were replaced. In the following model, this option was included in addition to the previous two alternatives and relaxed the constraint so that more than one alternative could be feasible. After replacing the bottleneck machines, the new average production speed would equal about 290-300 cans/min. Therefore, the average monthly capacity is 90 truckloads. Using average cost values obtained from Elmar, an industry leader in manufacturing and designing a wide variety of machines (http://www.nov.com/elmar/), the annual equivalent of expanding the capacity cost was estimated to be KD 11,522/year.

L.P. Model for Increasing Capacity of Existing Factory:

Input Variables:

Cij : Cost of transporting one truck from i to j.
Dj : Demand of j.
Ki : Capacity of i.
Ui : Increase in capacity of i.

Decision Variables:

Yij : Whether j is covered by i or not.
Si : Whether a factory exists or is established at i or not.
Tij : Whether the new trucks are used to transport from I to j.
Qi : Whether the capacity of factory i is increased or not.

Objective Function:

$$\text{Min } Z = \sum_{\substack{1\le i\le 3\\ 1<j<7}} \text{CijDjYij} + \sum_{i=1}^{3} \text{AiSi} + \sum_{\substack{1\le i\le 3\\ 1<j<7}} \text{CijDjTij} + \sum_{i=1}^{1} \text{AiQi}$$

Constraints:

$$\sum_{i=1}^{3} \text{Yij} + \text{Tij} = 1 \qquad j = 2, 3$$

Ensures that the demand of every market is supplied by one factory using one mode of transportation.

$$\sum_{i=1}^{3} \text{Yij} = 1 \qquad j = 1, 4, 5, 6, 7$$

Ensures that the demand of every market is supplied by one factory.

$$\text{Yij} \le \text{Si} \qquad i = 1, 2, 3 \text{ and } j = 1, 2, \ldots, 7$$

Ensures that a factory can only cover a market's demand if it exists or is established.

$$\sum_{j=1}^{7} \text{DjYij} + \text{DjTij} \le \text{KiSi} + \text{QiUi} \qquad i = 1, 2, 3$$

Ensures that the demand supplied by a factory by one mode of transportation does not exceed its capacity.

$$\sum_{i=2}^{3} \text{Si} = 1$$

Ensures that only one new factory is opened in either K.S.A. or Kuwait.

$$S1 = 1$$

Ensures that Kuwait Plant Exists.

$$\text{Yij} = \{0,1\}$$

Whether a market i is supplied by a factory j or not.

$$\text{Si} = \{0,1\} \qquad i = 2,3$$

Whether a factory is established at KSA or Kuwait

Output Results for Increasing Capacity of Existing Factory:

Results showed that increasing the capacity of the existing plant in Kuwait is the best option alongside using the new modes of transport. The results are summarized in Table 7.

Table 7. Model 3 output results.

D_jY_{ij}	Kuwait	KSA	UAE	Bahrain	Qatar	Oman	Iraq	Total Truckloads
Kuwait (old truck)	28	0	0	4	3	3	3	41
Kuwait (new truck)	0	3	3	0	0	0	0	6
								Total Cost = 13153 KD/month

S2 = 0; S3 = 0; Q1 = 1; T12 = 1; T13 = 1

Demand Increase and Forecasted Demand Case:
In the likely case of an increase in demand, decisions may change. Using the demand forecast for the next five years by the inventory control group, an average monthly demand was calculated, and the following results were obtained. Using the same model as case 3, results were obtained to develop a distribution plan to meet the forecasted demand.

Table 7. Forecasted average demand.

Demand City (j) Transportation Cost (Cij) per 2100 cartons (K.D.)								Monthly Capacity (x2100 cartons) (Ki)
(i)	Kuwait (1)	K.S.A. (2)	U.A.E. (3)	Bahrain (4)	Qatar (5)	Oman (6)	Iraq (7)	
Kuwait - Existing (1)	0	200	300	290	300	400	150	42
Kuwait - Potential (2)	0	200	300	290	300	400	150	90
K.S.A. - Potential (3)	200	0	100	90	100	200	350	90
FORECASTED-Monthly Demand (Di) (x2100 cartons)	33	8	7	5	4	4	7	Total Demand 68

Output Results for Forecasted Demand Case:
Results showed that establishing a factory in K.S.A. would be the most feasible solution in the case of an increase in demand in the future. Table 8 shows the results.

Table 8. Model 4 output results.

DjYij	Kuwait	KSA	UAE	Bahrain	Qatar	Oman	Iraq	Total Truck loads
Kuwait Existing	33	0	0	0	0	0	7	60
KSA Potential	0	8	7	5	4	4	0	5
Total Cost = 15181.00 KD/month								

S2 = 0; S3 = 1; Q1 = 0; T12 = 0; T13 = 0

6. Conclusion

Throughout this analysis, alternatives were studied in order to overcome the problem regarding the production capacity of the factory. The alternatives studied were whether to increase the capacity of the current factory, establish a new factory, and, also, to reduce shipping costs, new modes of transportation were introduced where the unit shipping cost is less than the costs for existing modes.

With the current average demand, it is suggested to increase the capacity of the existing Kuwait factory and use the new modes of transportation introduced. The initial associated transportation costs were 14,880 KD/month; the cost resulting from the suggested distribution plan is 13,153 KD/month, resulting in savings of 11.6%.
Since the canned food company is becoming more and more known throughout the region and internationally, there is an expected increase in demand, which the company may not satisfy with its current production capacity. It is safe to assume so because the company workers are already working overtime to satisfy the current demand. Therefore, it would seem necessary for the company to increase its production capacity to satisfy the future forecasted demand. This study shows the importance of optimization in reducing total costs in supply chain system operations. Operation managers can use the procedures outlined in this paper to reduce their operational costs in their supply chain systems.

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Biographies

Mehmet Savsar is a Professor of Industrial and Management Systems Engineering at Kuwait University, Kuwait, and Department of Industrial Engineering, Uskudar University, Turkey. He received his B.Sc. degree from Karadeniz Technical University, Turkey, in 1975; his M.Sc. and Ph.D. degrees from the Pennsylvania State University, the U.S.A. in 1978 and 1982, respectively, in Industrial Engineering and Operations Research. He worked as a researcher in Pennsylvania State University during 1980-1982; as a faculty member in Anadolu University, Turkey during 1982-1984; and in King Saud University, Saudi Arabia during 1984-1997. He has been with Kuwait University since 1997 and Uskudar University since 2020. He served as the Chairman of the Industrial and Management Systems Engineering Department at Kuwait University during 2006-2010. His research interests include modeling of production systems; quality, reliability, and maintenance management; facility layout; flexible manufacturing; and scheduling. He has over 200 journal and conference publications in international journals and conferences. He is on editorial boards of several international journals and conferences.

Mohammad J. Ben Salamah graduated from Kuwait University in 1996 with a Bachelor of Science in Electrical Engineering. From 1996 until 2000, he was employed as an Operations Engineer at the Operations Section of the Pumping Stations Department, part of the Public Authority for Industry of Kuwait. In 2000, he became the Operations Section Head and remained in that position until 2007. That year, Mohammad moved from the industry to academia and became an Instructor at the Higher Institute of Energy (HIE). In 2012 Mohammad Ben Salamah became the Quality Officer at the Higher Institute of Energy, where he remained in that position until 2018. From 2001, Mohammad Ben Salamah has joined the Ph.D. program at the Swinburne University of Technology, Melbourne, Australia, where he graduated with a Ph.D. in 2012. Mohammad's research interests include instrument drift detection, fault detection, metrology, statistical modeling, and reliability and maintenance optimization. He is also a referee at several scholarly journals. Mohammad's volunteer activities include being a member of ASQ, where he served as Vice Cahir of ASQ-Kuwait,2018-2019, and Chair in 2019-2020. In addition, he was a jury at the 2018 and 2019 ASQ MEA Quality Professional Award.