Modeling Supply Chain Network for a Poultry Industry in Oman: a Case Study

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Abstract

Supply chain management is an asset to every industry globally due to its positive outcomes such as faster response time, reduction of unwanted inventory and lower sales costs with enhanced customer service. It is therefore important to focus on improving the supply chain network of any industry. The objective of this research study is to model a supply chain network for poultry Industry in Oman. The study analyzes the existing supply chain network within a poultry industry and recommended its improvement based on the identified factors while giving more emphasis on the routing and distribution network aspects of supply chain. The recommendation, in the form of optimization model, is verified and validated using Lingo optimization software. Also, heuristic method is proposed and tested to overcome the complexity of optimization model.

Keywords

Supply and distribution network, routing, case study, Oman.

1. Introduction

Supply chain is the progression of organization, their facilities and operations that are included in manufacturing and delivering of a product or service. The progression starts with primal suppliers of raw materials and ends to the costumer. It includes all operations and facilities that are accomplished to provide a product or service (Beamon, 1998; O'Keeffe, 1998; Farahani, 2014). Facilities involve factories, warehouses, processing department, distribution department, offices, etc. Operations involve inventory management, forecasting, purchasing, scheduling, production, quality control, etc. There are two types of movements in the supply chain system: (i) movement of physical material in the same direction of the chain, and (ii) interchange of information that transfers in both directions of the chain.

Supply chain management (SCM) is very important in business nowadays due to the complexity of the systems overlapping each other. Therefore, the number and type of organizations within a supply chain network depend on the complexity and category of the organizations, whether it is manufacturing or service oriented. Obviously, manufacturing organization is more complicated than service organization. The performance of the supply chain depends on the policies and activities that are done during the production process, which is located in the middle of the chain (Beamon, 1999). Therefore, the production affects the flow of material and information. It also determines policy and rules that are implemented to coordinate all stations together in the chain.

The purpose of SCM is to improve efficiency and effectiveness of companies, which directly affect profits and minimize costs. Supply chain management is very critical to have successful business (Georgiadis et al., 2005: Kumar and Nigmatullin, 2011). It deals with major issues including global expansion and sourcing, fluctuation of oil and gas prices, the rapid growth of multinational companies, etc. The task of implementing comprehensive idea of supply chain management is not easy at all. However, if it has been put into place, every component within the chain greatly gains benefit (Gunasekaran et al., 2004; Mutha and Pokharel, 2009).

The objective of this research is to design a supply chain network of poultry oriented industry with an aim of increasing benefit by reduce operating cost. To reach this objective we studied the current supply chain network used in the case industry and evaluate it. Thereafter, we identify the constraints and the challenges that affects the supply chain network and then design the best routes for distribution network. Further we implement and evaluate the obtained network using optimization software.
The rest of the paper is structured as follows. Section 2 describe in brief the case company under the study. Section 3 presents and discusses proposed mathematical model. Section 4 is dedicated to the numerical analysis. Finally, section 5 gives the concluding remarks and future research works.

2. Description of the case industry

The case company is a big poultry industry situated in Oman. The industry is breeding poultry products, such as chickens, turkeys, ducks, geese for meat, egg and other related products. It has a production capacity of 17,000 million tons of meat products annually and enjoy 25% share of Oman's poultry consumption. It produces and deliver the products to many wholesale and retail outlets throughout Oman. The meat items are either delivered fresh or in a frozen form. One major issue facing the company is to identify the best distribution network based on available trucks and with respect to fluctuating demand. Apart from that there are several studies, which proved that the rapid increase of consumers' awareness against their daily food and the regular changes of global economics decrease the attractiveness of poultry industry. Other factors such as competition of rivalry, power of buyers and also higher threats from substitutes are some other concern of company. There are three important responsibilities of the case industry:

1) Constructing the distribution network in the country that enables it to make overall control of distribution process.
2) Operations, which include several methods of managing inventories and other methods that help to support the overall value of the process.
3) Marketing sector, which increases the competitiveness of the company.

Evan though the case company is facing many challenges as discussed above, the focus of this study will be on improving the distribution network.

3. Mathematical formulation to design the supply network

The objective here is to minimize the total transportation distance covered by truck while distributing products to the outlets. For developing a model, it is assumed that all trucks are identical in term of capacity and the planning horizon of delivery is for a week. Following are the index and parameters used in the optimization model.

Notations
n = number of clusters
k = truck index (k = 1, ……….., NV)

Parameters
NV = number of trucks
C_k = capacity of truck k
Q_j = demand quantity at point j
d_{ij} = shortest distance from point i to j
p_j = processing time at point j
t_{ij} = transportation time from point i to j
T_k = maximum time allowed for truck k
S = Subset of nodes

Binary Variable

$$x_{ij}^{k} = \begin{cases} 1, & \text{if truck } k \text{ travel from point } i \text{ to point } j. \\ 0, & \text{otherwise.} \end{cases}$$

Objective function

Min $\sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{NV} d_{ij} \quad x_{ij}^{k}$ ………………………………………………………………………… (1)

Subjected to:

$\sum_{i=2}^{n} \sum_{k=1}^{NV} x_{ij}^{k} = 1$ $\qquad j = 2, \ldots, n$ (2)

$\sum_{j=2}^{n} \sum_{k=1}^{NV} x_{ij}^{k} = 1$ $\qquad i = 2, \ldots, n$ (3)

$\sum_{i=1}^{n} x_{ip}^{k} - \sum_{k=1}^{NV} x_{pj}^{k} = 0$ $\qquad p = 1, \ldots, n, \quad k = 1, \ldots, NV$ (4)

$\sum_{i=1}^{n} \sum_{j=1}^{n} Q_j \, x_{ij}^{k} \leq C_k$ $\qquad k = 1, \ldots, NV$ (5)

$\sum_{i=1}^{n} \sum_{j=1}^{n} p_j \, x_{ij}^{k} + \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij} \, x_{ij}^{k} \leq T_k$ $\qquad k = 1, \ldots, NV$ (6)

$\sum_{i \in s} \sum_{j \in s} x_{ij}^{k} \leq |S| - 1$ (7)

$x_{ij}^{k} \in \{0, 1\}$ (8)

The objective function is shown by Equation (1). It minimizes the total travel distance. In the equation if the nodes *i* and *j* is selected for truck *k* then the value of $x_{ij}{}^{k}$ will be 1, otherwise it will be zero. In the model node 1 is assumed to be a warehouse/ depot from where the truck will start journey and come back after delivery. Equations (2) and (3) define that only one truck can reach at each outlet in the route to satisfy demand and then come back to the main warehouse. Constraints (4) establish that the truck entering into any node must leave it and goes to another node or the warehouse. Equation (5) imposes a constraint on tuck capacity. Equation (6) shows that the sum of total processing and transportation time should be less than or equal to the maximum allowed time for each truck in each round. Constraint (7) prevent any sub tour between nodes. Finally, Constraints (8) define the binary requirement for the variable.

4. Numerical analysis

4.1 Data collection

The data was collected from the case industry, survey and through observation.. The collected data unfolds the issues and the significance of the distribution network that is implemented. Survey has been done about the case industry Delivery Service in Muscat region. This survey has focused on medium hypermarkets and stores outlets where same truck can be used to satisfy more than one outlet due to medium demand. All trucks that are used by the case industry are monitored and tracked using GPS. In addition, the case industry uses a barcode system in order to monitor the sales and the inventory level of each product. This kind of information is used by the market analysis in the company and shared with managers and other representatives. Table 1 shows the different types of trucks, number of trucks and average monthly demand in each region.

Table 1. Number and types of trucks and demand

Branches	Type of trucks	Number of trucks	Demand Qty (kgs)/month
Muscat	3.5 ton	22	883,152
	5 ton	1	
	18 ton	2	
Saham	3.5 ton	4	145,137
Salalah	3.5 ton	4	186,727
Nizwa	3.5 ton	3	106,820
Al-Kamil	3.5 ton	3	107,058

We used Google map to assign places of shops that need the case industry products to be supplied. In addition, we have calculated distances between all these shops by using Google map. The time required between each shop to another has been assumed taking in consideration traffic and road works. The state of the roads in Muscat area has been studied in order to assume the time accurately. In the initial phase we considered only one cluster consisting of ten shops. These shops were selected based on their need and locations. A survey was conducted and data collected in order to understand the demand and needs of each of these shops (shown in Table 2). Table 3 and Table 4 displays the distance and travel time respectively between shops, represented here as nodes. In the table node 1 represents depot.

Table 2: Demand in the different shops in Muscat region

No.	Shop	Demand kgs
1	Warehouse	0
2	Al Gadir	600
3	Al Hadir	600
4	Masri mosque	400
5	Rawabi Magyoth Trade. &Cont.	300
6	Modern Muscat Shopping Center	700
7	Umm Ammar	600
8	Yanabea Al Ataa Modern	400
9	Al Bader	900
10	Khoudh 6th	800
11	Al Maqar	600
	Total	5900

Table 3. Distances between Nodes (kilometer)

	1	2	3	4	5	6	7	8	9	10	11
1	-	22.6	23.0	22.3	22.9	22.5	22.7	23.0	26.5	26.1	27.6
2	22.0	-	1.7	1.6	0.45	2.8	2.0	2.1	9.3	10.1	8.9
3	22.2	1.7	-	1.3	1.5	1.8	0.28	0.80	8.3	8.5	8.0
4	21.5	1.6	1.3	-	1.4	2.0	1.4	1.8	8.8	9.0	8.4
5	22.1	0.45	1.5	1.4	-	3.2	1.8	2.2	8.9	9.1	8.6
6	20.7	3.4	2.1	2.0	3.2	-	1.5	2.4	8.3	8.5	7.9
7	21.9	2.0	0.54	1.4	1.8	1.5	-	0.85	7.3	8.0	7.0
8	22.5	2.1	0.85	1.8	2.2	2.4	0.75	-	8.2	8.4	7.9
9	24.9	9.3	7.6	9.3	8.8	8.2	7.2	7.6	-	0.50	2.0
10	24.5	10.1	8.4	10.0	9.7	8.5	7.9	8.4	0.50	-	2.1
11	26.1	8.9	7.3	9.0	8.5	7.9	6.8	7.3	2.0	2.1	-

Table 4. Travel time between Nodes (minute)

	1	2	3	4	5	6	7	8	9	10	11
1	-	32	31	29	31	27	30	32	26	25	29
2	31	-	7	7	2	7	8	8	16	17	15
3	30	7	-	4	6	5	2	2	14	14	13
4	28	7	4	-	6	6	5	7	15	16	14
5	29	2	6	6	-	8	7	8	15	16	14
6	26	9	5	6	8	-	4	7	14	15	13
7	29	8	2	5	7	4	-	3	15	15	13
8	31	8	2	7	8	7	3	-	14	15	13
9	26	16	14	15	15	14	15	14	-	2	5
10	25	17	14	16	16	15	15	15	2	-	5
11	29	15	13	14	14	13	13	13	5	5	-

4.2 Results Discussion

The collected information's was analyzed using a mathematical model developed in section 3. For the analysis Lingo optimization software was used to obtain the optimal route for distributing the case industry product in Muscat area. Even though 11 nodes (10 shops + the warehouse) were considered as discussed in 4.1, the version of Lingo that was used could generate optimal solution only up to 7 nodes as shown in Table 4. To resolve this issue, we suggested a heuristic method.

Table 4. Lingo result for the test case

Number of nodes	# trucks	Run Time	Number of iterations	Total Number of variables	Objective function (KM)
3	3	0.0	162	30	46.5
	6	0.0	264	48	46.5
4	3	0.0	757	56	47.1
	6	0.01	2305	92	47.1
5	3	0.01	3943	90	46.85
	6	0.01	4700	150	46.85
6	3	0.07	93276	132	90.05
	6	0.11	82615	222	90.05
7	3	0.13	134118	182	90.8
	6	1.16	581709	308	90.8
8	3	infinity	infinity	240	None
	6	infinity	infinity	408	None

4.2.1 Heuristic Method

As the problem we are solving is NP hard in its strongest sense, we propose a heuristic method to solve complex problem in a reasonable timing. Divide and conquer algorithm is one type of heuristic algorithms. This algorithm splits the main problem into smaller sub problems that can be solved easily. Solutions of these small problems is then combined to a solution of the original one. For the data as shown in Table 3 we divide the problem into two sub problems with each problem consisting of 6 nodes (5 outlet and a warehouse). In the process of dividing, the geographical information of the outlets was considered. It means that the outlets with the least distance between them were clustered into the same group. The result of 11 nodes using proposed heuristic method is as shown in Table 5.

Table 5. Result for 10 outlets using heuristic method

Cluster	Distance (KM)	# iteration	Run time	Route	
				Truck 1	Truck 2
Cluster 1	90.3	33892	0.16	1-4-3-2-5-1	1-6-1
Cluster 2	100	19356	0.11	1-11-9-10-1	1-8-7-1

The result from the heuristic methods show that the company needs 4 trucks to cover a total distance of 190.3 kilometers. A couple of trucks are assigned to 5 outlets (4, 3, 2, 5 and 6) and the rest to another 5 outlets (11, 9, 10, 8 and 7). The delivery route for each truck is as shown in the last two columns of Table 5. The route shows that the truck will return to the main warehouse after the delivery. This route ensures that all the demand of outlet being considered in the analysis is satisfied.

Next, we check the percentage reduction in the movement of trucks by the heuristic method as compared to the existing practice. Heuristic method found that 4 trucks are needed to cover 190 km. Assuming that the truck needs at least 15 minutes to load, and the truck can only leave the warehouse twice, a truck will cover on average 95 km per day (190/4)*2=95. Assuming that the company works 6 days a week and the truck operates 26 days per month, in total a truck will cover 2470 km on average per month. Therefore,

% reduction = [(3609-2470)/3609*]100% = 31.5%

In the above equation 3609 shows the total km truck travels per month on average at present. This shows that by using the proposed method the reduction in the distance by truck will be 31.5% which is very significant. Thus, such a significant reduction will have considerable impact on fuel costs, maintenance costs, and cost of depreciation.

5. Conclusions

This study attempt to develop a supply chain network for poultry industry based in Oman. For the purpose, a mathematical model is developed and tested with respect to the real data collected from the case company, as well as, through market survey. Test using Lingo optimization software shows that medium and big size problem cannot be solved within reasonable computational timing. Therefore, to solve large scale industrial problem a heuristic method is proposed which divides the overall problem into multiple-sub problems. The test of heuristic method for medium size problem generates satisfactory result. Numerical result shows that the proposed method can reduce travel distance of up to 31.5% with respect to the existing system.

The research needs further testing of heuristic method for solving big size problem. Also, there is a need to validate the result of algorithm with respect to optimal solution obtained from the mathematical model.

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Biography

Mohammad Khadem is working as an Assistant Professor at Department of Mechanical and Industrial Engineering, Sultan Qaboos University, Muscat, Sultanate of Oman since September 2005. He received his PhD from University of Wisconsin, Milwaukee, USA in 2004. He received his Master of Science (Mechanical Engineering) degree from the University of South Alabama, USA in 2001. His research interest lies in the area of Simulation and Optimization, Decision Support System, Intelligent Manufacturing System, Lean Manufacturing, Flexible Manufacturing System, Logistic and Supply Chain, Production Planning and Control. He has published several research papers both in international journals and in conference proceedings.

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