FACILITY LOCATION AND ALLOCATION IN A SUPPLY CHAIN NETWORK OF A MANUFACTURING FIRM

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Abstract

This study is aimed at minimizing total cost in the supply chain network. The objectives involved optimal facility location and allocation decision as well as measuring the impact of disruption in change in supplier prices and transportation cost. This was achieved by the use of a single objective, multi-period, deterministic and centralized supply chain model, whereby products were allocated optimally across the Warehouses and DC's in the supply chain network and the facilities were located in such a way as to minimize the total cost involved in running the supply chain. The methodology used was the Mixed Integer Linear Programming (MILP) modelling approach to formulate the supply chain problem to determine the optimal facility location and product allocation in the supply chain network. The findings showed that the total cost is effectively reduced with the adoption of the scientific method of linear programming instead of the analytical and the rule of the thumb methods. Findings also showed that the increase a supplier's price and cease in a transportation type had minimal impact on the total cost. Also, a renewed optimized setting was achieved with the addition of extra facilities in several locations into the supply chain network which further reduced the total cost by 63.6% from ₦ 8,006, 901, 000 to ₦ 2, 914, 400,000. In conclusion, the whole idea behind this research is to provide a universal platform for the decision makers running a firm to take and implement their managerial decisions. The feasibility can be achieved by incorporating the framework into the company's infrastructure. It is recommended that cost optimization problems in a supply chain must be solved with appropriate scientific approaches by managers to achieve high efficiency in facility location and allocation decisions. Proper and adequate training of supply chain managers in the use of these scientific methods for planning and implementation is also recommended.

Keywords: Facility Location, Facility Allocation, Mixed Integer Linear Programming (MILP) and Total Cost Optimization

Introduction

The call to accomplish a worthwhile and effervescent supply chain network have become pivotal due to the increasing market competition, variable customer demands and the fast development of the economic and technological globalization. An efficient supply chain network promotes quick response to the customers' demands and hence, achieves success of the supply chain which depends on the cooperation and coordination among all members. Supply chain network design incorporates both strategic and tactical decisions on the number, location, capacity, and mission of the supply, production, and distribution facilities required to provide goods to a customer base. (Klibi and Martel, 2013). Over the years, various mathematical models have been developed to solve supply chain network design problems. Nagurney (2010) developed a modelling and analytical framework for the design of sustainable supply chain networks. Bashiri (2012) proposed a mathematical model for strategic and tactical planning in multi-dimensional network. Mahdi (2015) indicated that the supply chain network design can significantly affect the economic viability of a biofuel technology and developed a mixed- integer linear programming to determine the optimal supply chain design and operation under uncertain environment.

Statement of the problem

Decision making in companies which ensures that production planning, transportation and inventory levels in a supply chain must be adopted in order that customer demand is satisfied at minimum cost. According to (Uzor and Nnanna, 2018), companies and researchers need to take an integrated view of the total supply chain and since the supply chain includes two main inter-related processes firstly, production planning which deals with what quantity of product to produce considering possible disruptions in parameters such as supplier's price and transportation and inventory control which deals with storage of goods. Secondly, the supply chain deals with distribution and logistics that determines how to transport products to customers Ballou (2007).

(Uzor and Nnanna, 2018) identified that only one constituent of the overall supply chain network problem is often considered at a given point in time instead of the whole network.

While various studies have been carried out on optimization of supply chain network for manufacturing firms in Nigeria, there been no study on the integrated design of supplier selection in the supply chain network and the effect of disruptions in the network. Hence, this study attempts to fill the gap by adopting a scientific approach to determine where to site extra facilities that is, warehouses and DC's, production quantity, what best allocation of products should be made to the warehouses, distribution centres (DC's) to minimize inventory cost both at plant and DC's, transportation cost alongside with the effect of disruptions in the supply chain network.

Research Objectives

The specific objectives are to:

i. determine the optimal location of distribution centres of Nigerian Bottling Company's supply chain.
ii. investigate the quantity of products to be allocated between members of each echelon in the supply chain based on existing and emerging markets of the Nigerian Bottling Company.
iii. investigate the effects of disruption of supply prices and transportation significant on the Nigerian Bottling Company's supply chain.

Literature Review

Conceptual Definition of Supply Chain

Although industry and academia have investigated the concept of supply chain management for the last decade, there is still no consistent definition of the concept. As a result, there is generally a lack of consistency in meaning and clarity across the diverse definitions of supply chain management available in the literature.

Persson (1997) opined that supply chain management is a homogenous management concept. The overall objective of supply chain management is to contribute to improvements in the company bottom line or profitability.
Bolumole (2000) has concluded that supply chain management offers an integrated philosophy for managing organizations' purchasing and distribution processes based on a marketing perspective.

Also, Supply chain management is the management of the flow of goods and services and includes all processes that transform raw materials into final products. It involves the active streamlining of a business's supply-side activities to maximize customer value and gain a competitive advantage in the marketplace.

The supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers and customers. Within each organization, such as a manufacturer, the supply chain includes all functions involved in fulfilling customer requests. These functions include new product development, marketing, operations, distribution, finance, and customer service. Supply chain management involves the management of flows between and within stages in a supply chain to maximize total profitability Chopra (2001).

Supply chain management is the integration and management of supply chain organizations and activities through cooperative organizational relationships, effective business processes, and a high level of information sharing to create high performing value systems that provide member organizations sustainable competitive advantage Handfield (2002).

Methodology

Since this research used data from an existing company, it lies within the real-life context.

Thus, this study employed the case-study research design to optimize an existing supply chain network in the South-South and South East geo-political zones of the Nigerian Bottling Company in Nigeria.

Population of the study and sample

This study considered the Nigerian Bottling Company supply chain network in the South-South and South-East of Nigeria. There are twenty-two distribution centres in these three regions and three plants. Also, there are eight (8) extra distribution centres and a warehouse that are to be added to the network. All twenty-two distribution centres and three plants are considered. The time frame of this study spanned between 2009 – 2017, a nine-year period of observation.

Source of Data

This study employed secondary data in its analysis. Data on total production costs and capacity, annual demand at depots, transportation costs and their distances obtained from published reports and articles made available online.

Method of Data Analysis

The Mixed Integer Linear Programming technique was used to formulate the problem because output values of some variables are expected to be in integers and some others in non-integer of continuous form that is, in fractional form from the model. The developed mathematical model was solved through the LINGO programming language software. The LINGO programming language is chosen for this work due to its high-level efficiency in integrating and solving of production, inventory and transportation problems.

Model Specification

The Mixed Integer Linear Programing (MILP) model was developed to design an integrated supply chain network considering some parameters significantly affecting the profitability such as cost. The model is composed of some mathematical equations used to determine the numerical values of some decision variables (production rate, product flow rate in between echelons, inventory level, warehouse and distribution centre‘s capacity as well as optimal location).

Model Data

Manufacturer Stage

PCap(i) – Capacity of plant i to manufacture the finished product
MIPCap(p,i) – Capacity of plant i to manufacture the p^{th} MIP item
Pprod(i) – Unit cost of manufacturing the finished product at plant i
TPROD(i,j) – Unit transportation cost for the finished product from plant i to warehouse j
CMIP(p,i,t) – Unit production cost of the p^{th} MIP item in plant i for time period t
α(n) – Number of raw material of type n required to produce one finished product
β(p) – Number of p^{th} MIP item required to produce one finished product

Warehouse Stage

WCap(j) – Capacity limit for warehouse j for storing finished product.
WInitialInv(j) – Initial Inventory of finished product at warehouse j
Hw(j) – Inventory holding cost per unit of finished product per unit time at warehouse j TWAR(j,k,m) – Unit transportation cost of the finished product from warehouse j to retailer k using shipment mode m
M1, M2, M3 – Maximum capacity limit for the number of units transported by each mode (6 Pallet truck = M1, 8 Pallet truck = M2 and 8 Pallet truck = M3)

Distribution Centre's Stage

R(k,t) – Demand for the finished product at retailer k in time period t
Hr(k) – Inventory holding cost per unit of finished product per unit time at retailer k
RCap(k) – Maximum inventory capacity at retailer k
RInitialInv(k) – Initial Inventory of finished product at retailer k

Model Decision Variables

All variables defined are non-negative.

Supplier Stage

Sα(n,h,t) – Binary variable denoting whether supplier h is selected in time period t for raw material n.
w(n,h,t) – Quantity of raw material n ordered from selected supplier h for time period t
u(n,h,i,t) – Quantity of raw material n transported from supplier h to plant i during time period t

Manufacturer Stage

v(n,i,t) – Quantity of raw material n reaching plant i in time period t
X(i,t) – Number of finished products manufactured at plant i in time period t
XMIP(p,i,t) – Number of p^{th} MIP item produced in plant i in time period t
y(i,j,t) – Number of finished products shipped from plant i to warehouse j during time period t

Warehouse Stage

z(j,k,t,m) – Number of finished products shipped from warehouse j to retailer k in time period t using transport mode m.

Distribution Centre's stage

RInv(k,t) – Cumulative inventory at retailer k at the end of time period t.

Mathematical Model

Objective function

$$\sum_{n,k,t} \left(cpu(n,h,t) * w(n,h,t) \right) + \sum_{n,h,i,t} \left(TSUP(n,h,i) * u(n,h,i,t) \right) + \sum_{i,t} \left(Pprod(i) * X(i,t) \right)$$

□ □□CMIP□□p, i, t □* XMIP□p, i, t □□□□TPROD □i, j □* y□i, j, t □□□ □□TWAR □ j, k, m□* z□ j, k, t, m)) p,i,t i, j ,t j ,k ,t ,m

□ □□Hw□ j□*□□ j, t □□□ □□Hr □□k □* RInv□k, t □

Subject to the constraints:

Qstd□n, h,t □□ Qstdset□n□* S□□n, h,t □□□n, h,t ……………………….4.1
w□n, h,t □□ SCap□n, h□* S□□n, h,t □□□n, h,t ……………………….4.2
w□n, h,t □□ SMin□n, h□* S□□n, h,t □□□n, h,t ……………………….4.3
□ S□□n, h,t □□ 1 □□ n,t………………………….4.4
□ S□□n, h,t □□□0,1□ □n, h,t …………………...4.5
w□n, h, t □ □ □u□n, h, i, t □□□□□□□□□□□□□□□□n, h, t ……….……….4.6
For t □ 2; □u□n, h,i,t □1□□ v□n,i,t □□□□□□□n,i,t ………………….....4.7
X □i,t □□ PCap□i□□ □i,t ……………………...4.8
XMIP□p,i,t □□ MIPCap□p,i□□□□□□□□□□□□□□□p,i,t ……………………….4.9
v□n,i,t □□ □□n□* X □i,t □□ □n,i,t ……………………….4.10
MIPRe q□p,i,t □□ □□p□* X □i,t □ □p,i,t ……………………….4.11
X □i,t □□ □ y□i, j,t □ □i,t ………………………4.12
□ □j,t □□WCap□j□□ □j,t ……………………...4.13
For t □1; WInitialn v□ j□□ □□ j,i□□ □z□ j, k,1, m□□□j……………...4.14
z□j, k,t,1□□ M1 □j, k,t…………………….4.15
z□j, k,t2□□ M 2 □j, k,t ……………………….4.16
z□j, k,t,3□□ M 3 □j, k,t ………………...…..4.17
RInv□k,t □□ RCap□k □ □ k,t ……………….……....4.18

Plant Data

Table 4.1: Plant data

	Owerri	Enugu	Port Harcourt
Production Capacity (number of units)	59098264	49648040	135352872
Production cost for finished product	17.95	17.95	17.98

Table 4.2 shows the three sets of plants adopted with their corresponding production capacities and production cost over the nine (9) year period.

Table 4.2: MIP (Materials in Plant) Items data (CO_2)

	Owerri	Enugu	Port Harcourt
Production Capacity (number of units)	70917914	59577648	162423445
Cost per unit for nine (9) time period	2, 3, 6, 5, 6, 8, 6, 8, 7	3, 4, 7, 6, 7, 9, 7, 6, 9	3, 6, 9, 7, 7, 8, 8, 7, 6

Table 4.3 shows the material-in-plant item (Carbon dioxide). This is the raw material items produced in the three plants but is needed for the overall production process. The above table also shows the production capacity of MIP item within each plants over the nine (9) year period of time.

We assumed that the unit transportation cost for shipping the raw materials from the suppliers to the plants, TSUP (a, h, i), is independent of the raw material, supplier, and plant:

TSUP (a, h, i) = Thi = 3 naira/case.
We assumed that the unit transportation cost of the finished product from plants to warehouses within the manufacturing facility is independent of the plant and warehouse:
TPROD (i,j) = Tij = 0.86 naira/case.

Table 4.3: Warehouse data

	P/H Warehouse	Enugu Warehouse 2	Owerri Warehouse 3
Initial inventory, WInitialInv(j)	87414061.2	99655308	99655308
Maximum holding capacity, WCap(j)	524484367.2	597931848	597931848
Inventory holding cost per unit time period, Hw(j)	178.14/unit	68.6/unit	68.6/unit

Table 4.4 below shows the initial inventory, maximum inventory capacity and average inventory holding cost data for twenty-two distribution centres of the Nigerian Bottling Company within the south-south and south east geo-political zones in Nigeria.

Table 4.4: Distribution Centre data

Table 4.5: Customer's Demand data at retailers (Units)

Table 4.5 above shows the retailer's customer demand data of the Nigerian Bottling Company from 2009 to 2017 within the south-south and south east geo-political zones in Nigeria.

Transportation Rates

The cost of transporting products from a specific source to a specific destination is a function of the distance between these two points. The warehouses at Owerri, Enugu and P/H are integrated with the plant.
Considering the relevant carrier and operational costs, the average transportation cost per case per kilometer is found to be 0.86 Naira in a round trip. A 4-pallet truck has a capacity of transporting 300 cases. A single pallet means 300/4 which is equal to 75 cases. Therefore, capacities of other trucks can be calculated by multiplying their pallet capacity by 75. The summary for all cases is presented in table 4.7

Table 4.6: Distribution Centres and their distances from the warehouses in kilometers (Source: Survey data from NBC)

	Owerri	Enugu	P/H
Owerri	0.00	147.00	99.00
Ekpoma	213.50	238.40	304.70
Ughelli	178.00	269.90	172.90
Enugu	147.00	0.00	236.00
Warri	206.50	298.30	161.10
Asaba	100.70	125.60	191.90
Agbor	158.00	182.90	249.20
Ahoada	74.60	219.40	69.50
P/H	99.00	236.00	0.00
Calabar	208.00	258.00	14730
Wukari	513.90	369.30	633.00
Ikot Ikpeme	97.90	175.90	128.00
Eket	170.10	248.00	114.40
Uyo	125.90	203.91	123.60
Onitsha	87.00	107.70	155.60
Aba	63.00	184.00	61.00
Umuahia	62.20	126.80	108.30
Orlu	37.70	124.80	81.70
Nnewi	71.70	105.30	162.80
Awka	94.00	66.80	186.10
Nsukka	201.80	60.90	284.70
Abakaliki	214.70	70.10	247.80

Table 4.7: Types of trucks and their capacity (Source: Survey data from NBC)

Type	Enugu	Owerri	P/H	Total	Enugu	Owerri	P/H
4 Pallet truck	15	15	15	45	4500	4500	4500
6 Pallet truck	8	8	8	24	3600	3600	3600
8 Pallet truck	6	6	6	18	3600	3600	3600

The company uses vender managed inventory and agents must fulfill minimum criteria to qualify for it. Agents owned trucks and their capacity are given in Table 4.9

Table 4.8: Warehouse to Distribution Centre transportation data

	4 Pallet Truck	6 Pallet Truck	8 Pallet Truck
Lead time of shipment	2 time period	2 time periods	2 time periods
Maximum Capacity limit (units)	2613600	2203200	1900800

Table 4.9: Average transportation cost in naira/case between Warehouse and Distribution Centre Locations (Source: Survey data from NBC)

	Owerri	Enugu	P/H
Owerri	0.00	124.95	84.15
Ekpoma	181.48	202.64	259.00
Ughelli	151.30	229.42	146.97
Enugu	124.95	0.00	200.60
Warri	175.53	253.56	136.94
Asaba	85.60	106.76	163.12
Agbor	134.30	155.47	211.82
Ahoada	63.41	186.49	59.08
P/H	84.15	200.60	0.00
Calabar	176.80	219.30	125.21
Wukari	436.82	313.91	538.05
Ikot Ikpeme	83.22	149.52	108.80
Eket	144.59	210.80	97.24
Uyo	107.02	173.31	105.06
Onitsha	73.95	91.55	132.26
Aba	53.55	156.40	51.85
Umuahia	52.87	107.78	92.06
Orlu	32.05	106.08	69.45
Nnewi	60.95	89.51	138.38
Awka	79.90	56.78	158.19
Nsukka	171.53	51.77	242.00
Abakaliki	182.50	59.59	210.61

Model Results

Table 4.14: Finished products transportation from plants to warehouses

Manufacturing Plant	Warehouse	Quantity Shipped
Owerri	1	7284505
Enugu	2	8304609
Port Harcout	3	12089030

Table 4.14 shows the quantity of products shipped from manufacturing plants to warehouses.

Table 4.15: Finished products from warehouses to retailers through distribution centres

Warehouse/ DC's	Owerri	Enugu	P/H
Owerri	8719050		
Ekpoma	617220		
Ughelli			6056530
Enugu		8669900	
Warri			6914800
Asaba			8774920
Agbor			5860420
Ahoada			8350500
P/H			5940500
Calabar	6257800		
Wukari			8293700
Ikot Ikpeme			8721700
Eket	7639200		
Uyo	7636600		
Onitsha	9200600		
Aba			9257200
Umuahia	7781500		
Orlu	6316500		
Nnewi	84688500		
Awka		8295900	
Nsukka		8708100	
Abakaliki		8589000	

Table 4.15 shows the volume of products shipped from warehouses to the retailers through the distribution centres.

Discussion of Findings

i. Facility Allocation

Analytical results of the NBC's network structure as indicated by Uzorh and Nnnanna (2018), shows that the total cost incurred in the supply chain network is N14, 309,689,102.80. However, results obtained in this study by using the optimizing technique shows that warehouse at Owerri supplies four (Ekpoma, Calabar, Eket and Uyo) DC's within the South-South and five (Owerri, Onitsha, Umuahia, Orlu and Nnewi) DC's within the south-east. The warehouse at Enugu supplies four (Enugu, Awka, Nsukka, and Abakaliki) within the south east. Also, the warehouse at P/H supplies nine (Ughelli, Warri, Asaba, Agbor, Aba, P/H, Ahoada, Wukari and Ikot Ikpeme) DC's within the south-south and one in the south-east (Aba). In the optimization approach, a built-in programming tool called LINGO is utilized. In this scenario, the total annual cost is found to be N8, 006,900,000.00 within the minimum inventory holding cost of N226, 666.67 per year. Thus, it resulted in N 58, 359,158.36 annual saving from the actual cost investigated with the analytical method which is N14, 309,689, 102.80. All the demand is met and all warehouse supply demands within their proximity.

Network Re-design

The basic problem with agents is that, they are not likely to travel longer distance to collect shipment. For instance, it is difficult to find distribution in towns located far from plants.

The total cost they incur coupled with their capacity to satisfy market largely hampers their performance. Besides, the opportunity the company loses is taken up by competitors right away. Therefore, it is better for the company to outreach as much markets as possible. Accordingly, with an extra plant in Benin City built into the supply chain network as well as DC's at Sapele Road, Ugbowo, Eyean, Uromi, Auchi, Mbaise, Eleme and Agbani towns some of which already have existing markets of the NBC's products such as Sapele Road and Eyean while others are emerging, the optimal solution is found to be N 2, 914, 400,000 as the total cost of demand allocation to both existing and new facilities taking into consideration all potential market locations, thereby achieving a cost reduction of 63.6% on the initial total cost (N 8, 006, 901, 000) obtained from optimizing the supply chain network without integrating the above facilities. This was achieved by formulating the problem with the mixed integer linear programming model. In the renewed network optimization, the Owerri warehouse which was used to supply four DC's in the south-south and its area is now utilized to supply four DC's within the south-south (Eket, Asaba, Calabar and Mbaise). Also its supplies six DC's within the south-east (Owerri, Onitsha, Aba, Awka, Orlu and Nnewi). Enugu warehouse which was used to supply one DC within the south-south and its area is now utilized to supply two DC's south-south (Wukari and Ikot Ikpeme). Also it supplies only one DC in the south-east (Umuahia). Port Harcourt (P/H) warehouse which was used to supply four DC's within the south-south and its area is now utilized to supply seven DC's within the south-south (Warri, Eleme, Agbani, Ahoada, Agbor, Mbaise and Uyo). Also its supplies two DC's within the south-east (Nsukka and Abakaliki). The Benin warehouse now supplies five DC's within the south-south (Auchi, Ugbowo, Uromi, Sapele Road and Eyean). In doing so, the company can increase its responsiveness by fully utilizing its whole capacity to supply itself. In this scenario a total of 4,726,841 units of product of market demands in cases which is equivalent to 354,513,124.3 units are achieved with all the demands are met.

ii. Disruption Effect

Two different conditions of disruption as uncertainties are simulated to study their effects:

Supplier Price Increase

For the case of illustration, if we assume that the second supplier doubles the prices (cost per unit), that is, an increase of price by 100% (see Appendix II for changed data in LINGO code) then we get a new global optimal solution for the total cost is N 8,466,912,000 naira. Hence, the total cost increases by 5.7%.

Cease of a type of transportation

Again, for the case of illustration, we assume that the second type of transportation between warehouses and distribution centres (6 pallet truck) ceases to function, that is, no units can be shipped using the second type of transport across the last two stages (see Appendix III for changed data in LINGO code). Then we arrived at a new global optimum solution of N 7,976,234,000 naira. The total cost decreases by just 5.8%. Consequently, there is not much of a significant change in the way in which the priority is given to the size or type of transportation as time progresses from the start to the end of the horizon.

Conclusions

The goal of this work was to develop a single integrated collaborative model for a three-stage supply chain involving most of the strategic and tactical decisions faced by a real world, such as assignment of production quantities, inventory levels, stock-outs and shipment amounts. The stages considered were manufacturers, wholesalers and retailers. The finished products were shipped to the warehouses.

Inventory holding cost was incurred at the warehouse stage. This inventory was shipped to the distribution centres using three different types of transportation to satisfy the customer's demand. There were capacity restrictions at every stage of the supply chain. The primary objective of the problem was to minimize the total cost incurred across all the three stages over multiple time periods. The underlying assumptions, variables and constraints were defined as per the problem description. This resulted in a mixed integer linear programming problem. The problem was solved with a set of simulated data using the optimization software, LINGO. The results obtained were tabulated and thus the model implementation was validated accordingly. Finally, the model was analyzed for certain risk conditions, such as, supplier price increase and disruption in a mode of transportation. The effective results were studied and its changes were discussed. The whole idea behind this research was to provide a universal platform for the decision makers running a firm to take and implement their managerial decisions. This kind of framework would also help them to develop strategies without any lack of communication. The feasibility can be achieved by incorporating the framework into the company's infrastructure.

Recommendations

Supply Chain network design in this thesis has a high economic benefit for the manufacturing company. Therefore, the following recommendations were made:

i. The manufacturing company should always adopt the use of optimization techniques rather than the use of analytical methods. This ensures efficiency in the use of the company's resources.

ii. New distribution centres should be established at Auchi, Uromi, Mbaise, Agbani and Eleme to serve the evolving markets in these places and to safe total costs.

iii. The mixed integer linear programming (MILP) developed and optimization techniques employed here will be good grounds for any similar companies with a need to design appropriate SC network thereby reducing their costs.

iv. The disruptive effect of the suppliers price only led to a 5.7% increase in the total cost incurred in the supply chain network. Hence, the choice of manufacturer's selection which largely depends on the quality of suppliers materials should not be influenced due to price increase.

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