Cost minimisation of product transhipment for physical distribution management

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The objective of this study was to determine the optimal allocation of shipments (least cost) of two manufactured products between depots and places of consumption. In this study, the least-cost method was used in solving the transportation algorithm using Tora 2.0 version software. The study was necessary because of the high operating costs associated with physical distribution when deliveries are not properly planned and considered with reference to alternative strategies. In contrast, significant savings can be achieved by using techniques available for determining the cheapest methods of transporting goods from several origins to several destinations. Cost minimisation is a very useful approach to the solution of transportation problems.

Introduction

Significant development and innovations in the area of physical distribution have helped to facilitate growth of the international and local domestic trade, as well as the transportation of freights from manufacturers to consumers. These innovations enhance knowledge sharing with regard to supply chain management, which links the integration of companies, market enlargement and relationships between transport networks to firms in the new business technology. The integrated network of the supply chain management transformation promotes faster and more reliable business transactions for shipments of both raw materials and finished products (James, Edwin & William 1994; Liu 2012).

The development of transport services and adequate infrastructure to handle freight flows therefore becomes an important factor of economic competition between regions. From this study the researchers observed that supply chain management is a recent development in the field of distribution and logistics, which helps trading and manufacturing companies, as well as the government, to distribute products within Nigeria. Many companies use the terms 'logistics' and 'supply chain' to describe a process in which internal and external units are merged to minimise cost and maximise profit in the transhipment performance to the consumer in terms of redistribution of their finished products (Nwaogbe, Ukaegbu & Omoke 2012). The management of transportation activities and functions is vital for efficient and effective distribution of passengers and freight services.

Freight transportation encompasses the movement of a wide variety of products, from comparatively low value-to-weight commodities such as grain, palm oil, crude oil and gravel, to high value-to-weight items such as computer parts, cosmetics, beverages and pharmaceuticals. It includes the transportation of easily perishable items such as fresh fruit and vegetables, a wide range of refrigerated items, and a growing number of time-sensitive items for which on-time delivery is crucial to business success. Products also need to be moved in an environmentally sound and socially acceptable manner.

The world is engaging in more trade than ever before. Worldwide merchandise trade (exports) is estimated to have grown from US$58 billion in 1948 to US$6168 b in 2000. Between 1960 and 2000, the worldwide production of merchandised goods grew more than threefold and the volume of international trade increased almost by a factor of 10 (WTO 2002). Freight distribution is now considered with more attention as productivity gains in manufacturing are increasingly derived from efficiency at terminals instead of from the efficiency of transportation modes (Rodrigue 1999). Ogwude (1993) suggests that the value of transit time and the standard deviation of transit time vary substantially between the two groups of industrial freight, with the revealed values being, in general, higher for consumer goods than for capital goods. Generally, international trade increasingly contributes to the amount and the nature of physical distribution. Thus, globalisation is now considered as having a major impact on goods exchange (Janelle & Beuthe 1997; McCray 1998; Pedersen 2000; Woudsma 1999).

Transportation erodes profit margins or increases product prices. However, unlike production, it does not improve its value or quality. The only value created in product distribution is providing products at the right time and place to the customers and as well the consumers. Hence, the objective is to reduce cost as much as possible whilst maintaining service. When this is kept in mind, cost optimisation becomes useful in complex transport networks as manual intervention is sub-optimal as complexity increases. Cost minimisation in the transportation model is the management of all necessary means of transportation routes in order to distribute various raw materials and finished products from the point of origin (i) to the point of consumption or destination (j) at a minimal cost. Such cost reduction is useful in making the market price of products affordable.

One of the main goals of a business is to maximise earnings under certain investment conditions (Long *et al.* 2009). As reducing costs of materials, equipment and labour is generally difficult in today's competitive market, businesses are more inclined to target logistics costs in this regard (Long *et al*. 2009). Logistics costs are related mainly to procurement and supply, the manufacturing process and after-sales services. For example, determining the appropriate location and size of safety stock would be an approach to protect against the uncertainties associated with supply chains at an acceptable cost (Bahareh 2011).

One of the most important and successful applications of quantitative analysis in solving business problems has been in the physical distribution of products, commonly referred to as transportation problems. Basically, the purpose is to minimise the cost of shipping goods from one location to another so that the needs of each arrival area are met and every shipping location operates within its capacity. However, quantitative analysis has been used for many problems other than the physical distribution of goods. For example, it has also been used to place employees in certain positions within an organisation (sometimes called the assignment problem) (Reeb & Leavengood 2002).

Producers contribute significantly to the supply chain and inventory plays a major role in the efforts to deliver the product at the right place and on time. Longer lead times when shipping products will result in the need for ordering larger batch sizes. If the transport can be optimised and the lead time reduced, the buffer will be removed and, in turn, inventory costs (capital costs) will be reduced. Furthermore, an efficient transport system will help to reduce inventory cost by minimising cost and time if the shortest route or network is found.

The supply chain is the lifeblood of the corporation and sales revenue depends on the efficiency of the supply chain and its effectiveness in delivering products (Dittman, Slone & Mentzer 2010). Indeed, product availability is a critical measure of the performance of logistics and the supply chain (Coyle, Bardi & Langley 2009). A problem at any of the logistics nodes can lead to unavailability of products to the various customers. Examples of problems that can disrupt the supply chain and lead to unavailability of either raw materials or finished products include demand-and-supply issues, product quality problems, and internal or external problems that affect the organisation.

Supply chain management not only results in many valuable logistical improvements such as reduction in costs and decrease in cycle time, but also makes companies more competitive in today's dynamic market (Viswanadham & Gaonkar 2003). Supply chain management is an integration of the business processes from the suppliers to provide products, services and information to the end customer and also adds value for the end user and other stakeholders (Lambert & Cooper 2000).

Good transportation modelling requires simplifying a model in such a way that what seems to accurately describe the relevant attributes of the problems in question is a valid representation of the real-life decision problem.

Very often, decision problems are modelled as a cost-minimisation problem, particularly in the case of network models. The reasoning is that the specific decision situation does not influence income, so cost minimisation would lead to optimal profit. However, very few businesses have fixed revenues and decisions influencing costs may eventually also influence income. For business problems, revenues are relevant in most situations; minimum costs are often achieved by doing nothing. The reason for doing something is normally to generate revenues. Thus, the objective of the transportation model is to maximise revenue at minimal cost; alternatively, the optimal cost would be achieved by doing nothing, which would generate no revenue (Rasmus 2010).

Generally, the transportation model is aimed at minimising logistics costs by considering both internal and external variabilities and taking into account the routes, vehicles and the warehouses that are available for easy logistics and supply chain management of the products (Lianfu *et al.* 2009).

A linear programming model aims to establish a trade-off amongst a change in plans and carrying and shortage costs under resource constraints (such as supply and demand constraints) for a multi-item production system (Kanyalkar & Adil 2009) Costs incurred as a result of a change in plans are related to the instabilities occurring under a rolling schedule. These instabilities in the chain affect, for example, setup and expedition costs as well as material plans, which can lead to shortage or excess of components (Bahareh 2011).

Jung *et al.* (2008) present a linear programming formulation that includes the control variables of safety stock with the purpose of minimising the total supply chain's inventory whilst meeting the service level target. This model incorporates nonlinear performance functions, the interdependence between the service level at upstream and downstream stages of the supply chain and the safety capacity constraints. Some of the assumptions applied in this model are that demand patterns and constant supply of the products are determined by the customers and the depots based on their demands. Furthermore, the demanded quantity of products will determine the type of vehicle that will be used to move the products, which, in turn, will determine the cost of the shipment.

There are three reasons why the integration process of physical distribution starts with finished goods. Firstly, finished goods are the largest single segment of inventory to be managed. Secondly, because of its profundity, visibility, and frequent contact with customers, finished goods distribution most directly influences customers' service expectations and performance. Thirdly, management of finished goods allows intervention in an important process without venturing into production processes or other powerful cost centres of the firm. That is, altering physical distribution management is a low-risk, high-gain endeavour compared with altering other functions.

Objective of the study

As a case study of the effect of supply chain management on cost minimisation, the operations of a soap manufacturing company in Nigeria, Godrej Nigerian Ltd., were considered. The company is part of the Godrej Group, based in India. It started operating in Nigeria in June 2010 and produces Tura soaps, creams and lotions.

The objective of the study was to determine the optimal allocation of shipments of two manufactured products between depots and the end users (i.e. to result in lowest cost). The study is necessary because of the high operating costs associated with physical distribution when deliveries are not properly planned and evaluated with reference to alternative strategies. In contrast, planning adds the most value in making complex cost decisions and reducing high operating costs.

Transportation models

A transportation model is concerned with the transport of goods from several supply locations to several customer locations. For physical distribution (transportation) of goods, supply locations (called origins) and a specified order Zhave to be matched with a variety of transportation routes and a variety of costs.

The structure of a transportation problem involves a large number of shipping routes from several supply origins to several demand destinations (Sharma 2009). Determining optimal routes to minimise costs associated with physical distribution management has been a serious challenge to managers. However, linear programming can be used to generate practical applications to the model, which often serves more as a theoretical framework than offering empirical solution.

The principal objective, therefore, is to formulate the problem of finding the minimum-cost route as a transhipment model and then solve the transhipment model by transportation techniques. In the transhipment model, a commodity is allowed to pass transiently through other sources and destinations before it reaches its final, designated destination. The entire supply from all sources could potentially pass through a transhipment point before the products are moved to their final destination, namely the distributors of the firm, who redistribute the products to wholesalers, retailers and the final consumers. This means that each source or destination node in the transportation network can be considered as both a transient source and a transient destination. Thus, the number of sources equals the sum of sources and destinations in the corresponding transportation model. The most important requirement of the transportation problem is advance knowledge of the method of distributing flows from each source to each destination, which is also a cost determinant. This view is corroborated by Sharma (2009).

The transhipment problem is concerned with allocating and routing flows of finished products or raw materials from a supply centre to the destination via intermediate nodes (transhipment nodes). Furthermore, supply centres generate a surplus that must be distributed and each destination generates a given deficit. Intermediate nodes neither generate nor absorb flow. The total supply must equal the demand; if not, dummy nodes should be introduced appropriately. An industrial organisation may utilise a large number of distribution channels to make finished goods available to its customers, who may be spread over a large area. The transhipment problem thus assumes great importance in any manufacturing company.

For most manufacturing companies in Nigeria it is not financially viable to transport directly from the factory to the various demand destinations. This is due to a lack of a good road network in many cities. The high costs involved, together with the prevailing market conditions, force the decision maker to consider alternative channels of transporting the company's products. As bad roads make it difficult for companies, especially the ones operating in the south-eastern part of Nigeria, to transport their products to their customers, they often employ third-party logistics firms that are involved with warehousing, transport or indirect transportation channels. The products are therefore transported through one or more intermediate stages before reaching the final customer (demand destination). This approach is adopted by many industries in Nigeria. For example, Godrej Nigeria Ltd., Promasidor Ltd. and European Soap Limited use an indirect transportation method, with Manufacturers Distribution Services (MDS) Logistics providing warehousing and other transport companies take care of transporting their products. Companies such as PZ Cussons PlC, Nigerian Breweries, Guiness Breweries and Rackit Benkiser use third-party logistics for distribution to their own warehouses.

Methodology

In solving a transportation problem, there are many methods that may be used. However, in this study we focused on the least-cost method. This model determines the initial solution and a feasible solution (i.e., it must satisfy all the supply and demand constraints) and also determines the optimal allocation of limited resources to meet given objectives. The resources may be labour, materials, goods, machines, vehicles or others. Tora 2.0 version software was used to run the analysis (Taha 2007).

Data analysis

Godrej Nigeria Ltd. has a soap factory at Aba. Between April 2011 and March 2012 it produced a total of 337 520 cartons of soap, of which 167 020 were Tura Medicated soap and 170 500 were Tura Supreme soap. The average quantity of soap supplied to the customer from the warehouses or depots and the quantity demanded by customers from these warehouses are given in Table 1 and Table 2, respectively as well as Table 3 and Table 4 for the transportation cost per carton to depots and customers.

Formulation of transportation model

A transportation model must include origins (i.e. plants or factories where products are produced) and demands of the finished products made by customers at various destinations. The reason for this is to achieve a certain objective, such as profit maximisation or cost minimisation. In this transportation model, let m factory (Aba) be the supplier of the products to n warehouses (Aba, Calabar, Enugu, Onitsha and Port Harcourt) (see Figure 1). Let the factory or source of supply i (i = 1, 2, 3……, m) produce a_i units and the destination j (j = 1, 2, 3,….., n) require b_j units. The cost of transportation from factory i to warehouse j is c_{ij}. The decision variable of this problem will be x_{ij}, which is the amount of transportation from factory i to warehouse j (see Table 5 and Table 6).

TABLE 1: Quantity supplied from factory to depots or warehouse.

Depot or warehouse	Quantity supplied (in cartons per year)		Total
	Tura medicated	Tura supreme	
Aba	12 625	37 375	50 000
Calabar	4519	13 298	17 817
Enugu	3275	9200	12 475
Onitsha	12 445	22 300	34 745
Port Harcourt	6575	5700	12 275
Total	**39 439**	**87 873**	**127 312**

Source: E. Akogu (Godrej Nigeria Limited) pers. comm., 09 April 2012

TABLE 2: Quantity demanded by customers from depot or warehouse.

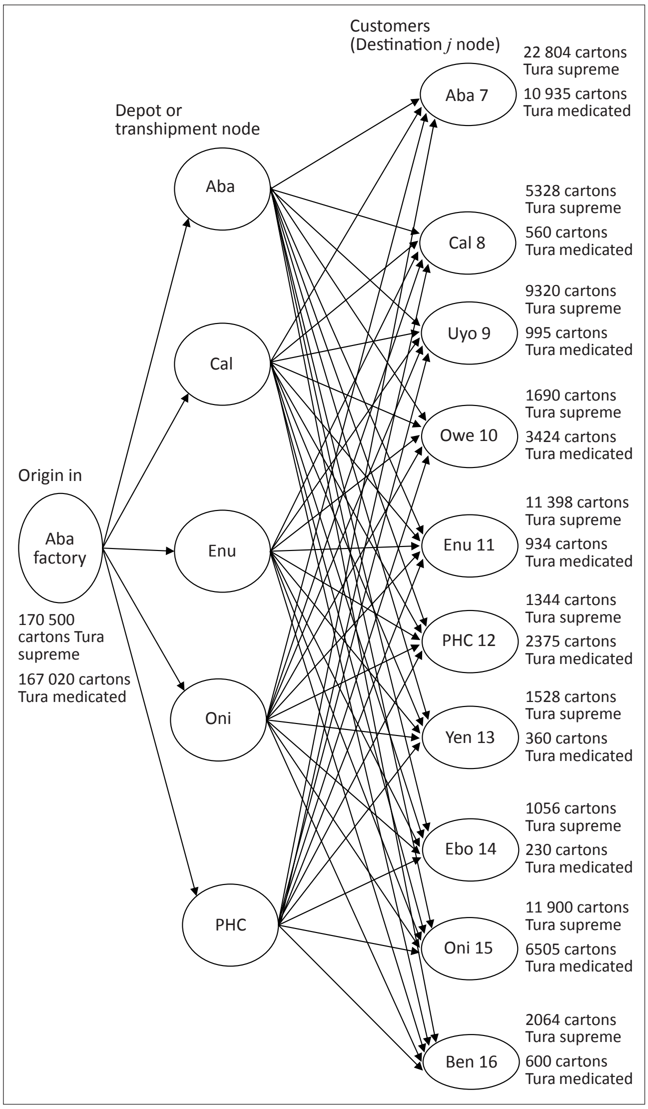
Customer or retailer	Quantity demanded (in cartons per year)		Total
	Tura medicated	Tura supreme	
Abia (Aba)	10 935	22 804	33 739
Imo	1690	3424	5888
Cross river	560	5328	10 315
Rivers	2375	1344	5114
Onitsha	6505	11 900	12 332
Ebonyi	230	1056	3719
Bayelsa	360	1528	1888
Enugu	934	11 398	1286
Benue	600	2064	18 405
Akwa-Ibom	995	9320	2664
Total	**25 184**	**70 166**	**95 350**

Source: E. Akogu (Godrej Nigeria Limited) pers. comm., 09 April 2012

TABLE 3: Transportation costs per carton factory to depots.

Factory	Depot				
	Aba	Calabar	Enugu	Onitsha	Port Harcourt
Aba	10	64	59	33	36

Source: E. Akogu (Godrej Nigeria Limited) pers. comm., 09 April 2012



Ben, Benue; Cal, Calabar; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

FIGURE 1: Network representation of Godrej distribution for south-eastern Nigeria.

TABLE 4: Transportation cost per carton depot to customers.

Depots	Customers									
	Aba	Yenegoa	Benue	Calabar	Uyo	Owerri	Enugu	Port Harcourt	Ebonyi	Onitsha
Aba	10	62	84	64	26	26	59	36	75	33
Calabar	64	93	90	10	30	90	85	84	80	97
Enugu	59	125	50	85	79	92	10	95	35	35
Onitsha	33	80	85	97	59	50	35	50	70	20
Port Harcourt	36	36	150	84	65	30	95	20	120	65

Source: E. Akogu (Godrej Nigeria Limited) pers. comm., 09 April 2012

$$\text{Min } Z = \sum_{i=1}^{m} \sum_{j=1}^{n} CijXij \qquad \text{[Eqn 1]}$$

$$\text{S.T. } \sum_{j=1}^{n} Xij = a_i, \text{ for } i = 1, 2, \ldots, m \qquad \text{[Eqn 2]}$$

$$\sum_{i=1}^{m} Xij = b_j, \text{ for } j = 1, 2, \ldots, n \qquad \text{[Eqn 3]}$$

$$X_{ij} \geq 0 \text{ for all } i \text{ and } j. \qquad \text{[Eqn 4]}$$

The feasible solution property: A transportation problem will have a feasible solution if, and only if:

$$\sum_{i=1}^{m} Si = \sum_{j=1}^{n} dj \qquad \text{[Eqn 5]}$$

Where: a_i = number of units being supplied by source i
d_j = number of units being received by destination j
c_{ij} = cost per unit distributed from source i to destination j
x_{ij} = amount distributed from source i to destination j.

TABLE 5: The pattern of distribution of products in the form of transportation matrix.

Factory of origin	Destination warehouse			Available products
	1	2	*n*	
1	x_{11}	x_{12}	x_{1n}	a_1
2	x_{21}	x_{22}	x_{2n}	a_2
m	x_{m1}	x_{m2}	x_{mn}	a_m
Demand	b_1	b_2	b_n	-

m, number of rows (demand); *n*, number of columns (supply).

Transportation problem modelling shows that:

x_{ij} = number of soaps produced in a year i for supply in a year j
c_{ij} = cost associated with each unit of x_{ij}
b_j = number of scheduled for supply in a year j
a_i = production of soaps in a year i

Discussion

Based on the analysis using the Tora software (Tables 7–14), iteration 9 (Table 15) gave the final, optimal solution model. From the transportation model output summary in Table 16, the total cost of transporting the products at minimal cost is N1 704 577. The result shows that the Aba depot has a surplus of 832 cartons of the product after supplying the quantity demanded from the depot or warehouse by the customers. A dummy variable is therefore introduced to balance the transportation model as the demand is not equal to supply of the product. The Aba depot is the most cost-effective supply point for Aba, Uyo and Owerri customers. The Calabar depot supplies Calabar and has a surplus of 11 929 cartons of the product; a dummy variable is introduced to balance the transportation model. The Enugu depot supplies Enugu, Ebonyi and Benue customers with the required quantity of the products. Furthermore, the Onitsha depot supplies customers in Onitsha and has a surplus of 12 533 units, thereby introducing a dummy variable to balance the model in order to run the analysis and have a successful result. Finally, the Port Harcourt depot supplies Port Harcourt and Yenagoa customers and has a surplus of 6668 unit.

TABLE 6: Input from warehouse to distributors.

Supply/Demand names	Aba	Cal	Uyo	Owe	Enu	Phc	Yen	Ebo	Oni	Ben	Supply
Aba	10	64	26	26	59	36	62	75	33	84	50 000
Calabar	64	10	30	90	85	84	93	80	97	90	17 817
Enugu	59	85	79	92	10	95	125	35	35	50	12 475
Onitsha	33	97	59	50	35	65	80	70	20	85	34 745
Port Harcourt	36	84	65	30	95	20	36	120	65	150	12 275
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**-**

Ben, Benue; Cal, Calabar; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

TABLE 7: Iteration 1.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = -23)	Uyo (V3 = -3)	Owe (V4 = -63)	Enu (V5 = 22)	Phc (V6 = -73)	Yen (V7 = -57)	Ebo (V8 = 47)	Oni (V9 = -3)	Ben (V10 = 57)	Dummy (V11 = 0)	Supply
Aba (U1 = 0)	0	64	26	26	59	36	62	75	33	84	0	-
	18 038	-	-	-	-	-	-	-	-	-	**31 962**	**50 000**
	0	-87	-29	-89	-37	-109	-119	-28	-36	-27	0	-
	64	10	30	90	85	84	93	80	97	90	0	-
Cal (U2 = 33)	-	**5888**	**10 315**	-	-	-	-	**504**	-	**1110**	-	**17 817**
	-21	0	0	-120	30	-124	-117	0	-67	0	33	-
	59	85	79	92	10	95	125	35	35	50	0	-
Enu (U3 = 12)	-	-	-	-	**12 332**	-	-	**143**	-	-	-	**12 475**
	-61	-120	-94	-167	0	-180	-194	0	-50	-5	-12	-
	33	97	59	50	35	65	80	70	20	85	0	-
Oni (U4 = 23)	**15 701**	-	-	-	-	-	-	**639**	**18 405**	-	-	**34 745**
	0	-97	-39	-90	10	-115	-114	0	0	-5	23	-
	36	84	65	30	95	20	36	120	65	150	0	-
Phc (U5 = 93)	-	-	-	**5114**	-	**3719**	**1888**	-	-	**1554**	-	**12 275**
	67	-14	25	0	20	0	0	20	25	0	93	-
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3 719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: Total cost (Objective value) = NGN 2277086. The costs for each iteration after analysis are indicated in bold.
Ben, Benue; Cal, Calabar; Dummy, dummy variable; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

TABLE 8: Iteration 2.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = 70)	Uyo (V3 = 90)	Owe (V4 = 30)	Enu (V5 = 22)	Phc (V6 = 20)	Yen (V7 = 36)	Ebo (V8 = 47)	Oni (V9 = 3)	Ben (V10 = 150)	Dummy (V11 = 0)	Supply
Aba (U1 = 0)	10	64	26	26	59	36	62	75	33	84	0	-
	18 542	-	-	-	-	-	-	-	-	-	**31 458**	**50 000**
	0	6	64	4	-37	-6	-26	-28	-36	66	0	-
	64	10	30	90	85	84	93	80	97	90	0	-
Cal (U2 = 60)	-	**5888**	**10 315**	-	-	-	-	-	-	**1614**	-	**17 817**
	-114	0	0	-120	-123	-124	-117	-93	-160	0	-60	-
	59	85	79	92	10	95	125	35	35	50	0	-
Enu (U3 = 12)	-	-	-	-	**12 332**	-	-	**143**	-	-	-	**12 475**
	-61	-27	-1	-74	0	-87	-101	0	-50	88	-12	-
	33	97	59	50	35	65	80	70	20	85	0	-
Oni (U4 = 23)	**15 197**	-	-	-	-	-	-	**1143**	**18 405**	-	-	**34 745**
	0	-4	54	3	10	-22	-21	0	0	88	23	-
	36	84	65	30	95	20	36	120	65	150	0	-
Phc (U5 = 0)	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	**5114**	-	**3719**	**1888**	-	-	**1050**	**504**	**12 275**
	-67	-14	25	0	-73	0	0	-73	-68	0	0	-
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: Total cost (Objective value) = NGN 2230214. The costs for each iteration after analysis are indicated in bold.
Ben, Benue; Cal, Calabar; Dummy, dummy variable; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

TABLE 9: Iteration 3.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = 70)	Uyo (V3 = 90)	Owe (V4 = 30)	Enu (V5 = 110)	Phc (V6 = 20)	Yen (V7 = 36)	Ebo (V8 = 47)	Oni (V9 = 3)	Ben (V10 = 150)	Dummy (V11 = 0)	Supply
Aba (U1 = 0)	10	64	26	26	59	36	62	75	33	84	0	-
	18 685	-	-	-	-	-	-	-	-	-	**31 315**	**50 000**
	0	6	64	4	51	-16	-26	-28	-36	66	0	-
	64	10	30	90	85	84	93	80	97	90	0	-
Cal (U2 = 60)	-	**5888**	**10 315**	-	-		-	-		**1614**	-	**17 817**
	-114	0	0	-120	-35	-124	-117	-93	-160	0	-60	-
	59	85	79	92	10	95	125	35	35	50	0	-
Enu (U3 = 100)	-	-	-	-	**12 332**	-	-	-	-	**143**	-	**12 475**
	-149	-115	-89	-162	0	-175	-189	-88	-138	0	-100	-
	33	97	59	50	35	65	80	70	20	85	0	-
Oni (U4 = 23)	**15 054**	-	-	-	-	-	-	**1286**	**18 405**	-	-	**34 745**
	0	-4	54	3	98	-22	-21	0	0	88	23	-
	36	84	65	30	95	20	36	120	65	150	0	-
Phc (U5 = 0)	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	**5114**	-	**3719**	**1888**	-	-	**907**	**647**	**12 275**
	-26	-14	25	0	15	0	0	-73	-68	0	0	-
Demand	**33 739**	**5888**	**10 315**	**5 114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: The costs for each iteration after analysis are indicated in bold.
Ben, Benue; Cal, Calabar; Dummy, dummy variable; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

TABLE 10: Iteration 4.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = -28)	Uyo (V3 = -8)	Owe (V4 = 30)	Enu (V5 =12)	Phc (V6 = 20)	Yen (V7 = 36)	Ebo (V8 = 47)	Oni (V9 = 3)	Ben (V10 = 52)	Dummy (V11 = 0)	Supply
Aba (U1 = 0)	10	64	26	26	59	36	62	75	33	84	0	-
	19 592	-	-	-	-	-	-	-	-	-	**30 408**	**50 000**
	0	-92	-34	4	-47	-16	-26	-28	-36	-32	0	-
	64	10	30	90	85	84	93	80	97	90	0	-
Cal (U2 = 38)	-	**5888**	**10 315**	-	-	-	-	-	-	**1614**	-	**17 817**
	-16	0	0	-22	-35	-26	-19	5	-62	0	38	-
	59	85	79	92	10	95	125	35	35	50	0	-
Enu (U3 = -2)	-	-	-	-	**11 425**	-	-	-	-	**1050**	-	**12 475**
	-51	-115	-89	-64	0	-77	-91	10	-40	0	-2	-
	33	97	59	50	35	65	80	70	20	85	0	-
Oni (U4 = 23)	**14 147**	-	-	-	**907**	-	-	**1286**	**18 405**	-	-	**34745**
	0	-102	-44	3	0	-22	-21	0	0	-10	23	-
Phc (U5 = 0)	36	84	65	30	95	20	36	120	65	150	0	-
	-	-	-	**5114**	-	**3719**	**1888**	-	-	-	**1554**	**12 275**
	-26	-112	-73	0	-83	0	0	-73	-68	-98	0	-
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: Total cost (Objective value) = NGN 2128744. The costs for each iteration after analysis are indicated in bold.
BEN, Benue; CAL, Calabar; Dummy, dummy variable; EBO, Ebonyi; ENU, Enugu; ONI, Onitsha; OWE, Owerri; PHC, Port Harcourt; YEN, Yenagoa.

TABLE 11: Iteration 5.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = -10)	Uyo (V3 = 30)	Owe (V4 = 30)	Enu (V5 = 12)	Phc (V6 = 20)	Yen (V7 = 36)	Ebo (V8 = 47)	Oni (V9 = 3)	Ben (V10 = 52)	Dummy (V11 = 0)	Supply
Aba (U1 = 0)	10	64	26	26	59	36	62	75	33	84	0	-
	21 206	-	-	-	-	-	-	-	-	-	**28 794**	**50 000**
	0	-54	4	4	-47	-16	-26	-28	-36	-32	0	-
Cal (U2 = 0)	64	10	30	90	85	84	93	80	97	90	0	-
	-	**5888**	**10 315**	-	-	-	-	-	-	-	**1614**	**17 817**
	-54	0	0	-60	-73	-64	-57	-33	-100	-38	0	-
Enu (U3 = -2)	59	85	79	92	10	95	125	35	35	50	0	-
	-	-	-	-	**9811**	-	-	-	-	**2664**	-	**12 475**
	-51	-77	-51	-64	0	-77	-91	10	-40	0	-2	-
Oni (U4 = 23)	33	97	59	50	35	65	80	70	20	85	0	-
	12 533	-	-	-	**2521**	-	-	**1286**	**18 405**	-	-	**34 745**
	0	-64	-6	3	0	-22	-21	0	0	-10	23	-
Phc (U5 = 0)	36	84	65	30	95	20	36	120	65	150	0	-
	-	-	-	**5114**	-	**3719**	**1888**	-	-	-	**1554**	**12 275**
	-26	-74	-35	0	-83	0	0	-73	-68	-98	0	-
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: Total cost (Objective value) = NGN 2067412. The costs for each iteration after analysis are indicated in bold.
BEN, Benue; CAL, Calabar; Dummy, dummy variable; EBO, Ebonyi; ENU, Enugu; ONI, Onitsha; OWE, Owerri; PHC, Port Harcourt; YEN, Yenagoa.

TABLE 12: Iteration 6.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = -10)	Uyo (V3 = 30)	Owe (V4 = 30)	Enu (V5 = 35)	Phc (V6 = 20)	Yen (V7 = 36)	Ebo (V8 = 70)	Oni (V9 = 20)	Ben (V10 = 75)	Dummy (V11 = 0)	Supply
Aba (U1 = 0)	10	64	26	26	59	36	62	75	33	84	0	-
	33 739	-	-	-	-	-	-	-	-	-	**16 261**	**50 000**
	0	-54	4	4	-24	-16	-26	-5	-13	-9	0	-
Cal (U2 = 0)	64	10	30	90	85	84	93	80	97	90	0	-
	-	**5888**	**10 315**	-	-	-	-	-	-	-	**1614**	**17 817**
	-54	0	0	-60	-50	-64	-57	-10	-77	-15	0	-
Enu (U3 = -25)	59	85	79	92	10	95	125	35	35	50	0	-
	-	-	-	-	**9811**	-	-	-	-	**2664**	-	**12 475**
	-74	-100	-74	-87	0	-100	-114	10	-40	0	-25	-
Oni (U4 = 0)	33	97	59	50	35	65	80	70	20	85	0	-
	-	-	-	-	**2521**	-	-	**1286**	**18 405**	-	**12 533**	**34 745**
	-23	-87	-29	-20	0	-45	-44	0	0	-10	0	-
Phc (U5 = 0)	36	84	65	30	95	20	36	120	65	150	0	-
	-	-	-	**5114**	-	**3719**	**1888**	-	-	-	**1554**	**12 275**
	-26	-74	-35	0	-60	0	0	-50	-45	-75	0	-
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: Total cost (Objective value) = NGN 1779153. The costs for each iteration after analysis are indicated in bold.
Ben, Benue; Cal, Calabar; Dummy, dummy variable; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

TABLE 13: Iteration 7.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = -10)	Uyo (V3 = 30)	Owe (V4 = 30)	Enu (V5 = 35)	Phc (V6 = 20)	Yen (V7 = 36)	Ebo (V8 = 70)	Oni (V9 = 20)	Ben (V10 = 75)	Dummy (V11 = 0)	Supply
Aba (U1 = 0)	10	64	26	26	59	36	62	75	33	84	0	-
	33 739	-	-	-	-	-	-	-	-	-	**16 261**	**50 000**
	0	-54	4	4	-24	-16	-26	-15	-13	-9	0	-
Cal (U2 = 0)	64	10	30	90	85	84	93	80	97	90	0	-
	-	**5888**	**10 315**	-	-	-	-	-	-	-	**1614**	**17 817**
	-54	0	0	-60	-50	-64	-57	-20	-77	-15	0	-
Enu (U3 = -25)	59	85	79	92	10	95	125	35	35	50	0	-
	-	-	-	-	**8525**	-	-	**1286**	-	**2664**	-	**12 475**
	-74	-100	-74	-87	0	-100	-114	10	-40	0	-25	-
Oni (U4 = 0)	33	97	59	50	35	65	80	70	20	85	0	-
	-	-	-	-	**3807**	-	-	-	**18 405**	-	**12 533**	**34 745**
	-23	-87	-29	-20	0	-45	-44	0	0	-10	0	-
Phc (U5 = 0)	36	84	65	30	95	20	36	120	65	150	0	-
	-	-	-	**5114**	-	**3719**	**1888**	-	-	-	**1554**	**12 275**
	-26	-74	-35	0	-60	0	0	-50	-45	-75	0	-
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: Total cost (Objective value) = NGN 1766293. The costs for each iteration after analysis are indicated in bold.
BEN, Benue; CAL, Calabar; Dummy, dummy variable; EBO, Ebonyi; ENU, Enugu; ONI, Onitsha; OWE, Owerri; PHC, Port Harcourt; YEN, Yenagoa.

TABLE 14: Iteration 8.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = 10)	Uyo (V3 = 26)	Owe (V4 = 30)	Enu (V5 = 35)	Phc (V6 = 20)	Yen (V7 = 36)	Ebo (V8 = 70)	Oni (V9 = 20)	Ben (V10 = 75)	Dummy (V11 = 0)	Supply
Aba (U1 = 0)	10	64	26	26	59	36	62	75	33	84	0	-
	33 739	-	**10 315**	-	-	-	-	-	-	-	**5945**	**50 000**
	0	-54	0	4	-24	-16	-26	-15	-13	-9	0	-
Cal (U2 = 0)	64	10	30	90	85	84	93	80	97	90	0	-
	-	**5888**	-	-	-	-	-	-	-	-	**11 929**	**17 817**
	-54	0	-4	-60	-50	-64	-57	-20	-77	-15	0	-
Enu (U3 = -25)	59	85	79	92	10	95	125	3	35	50	0	-
	-	-	-	-	**8525**	-	-	**1286**	-	**2664**	-	**12 475**
	-74	-100	-78	-87	0	-100	-114	0	-40	0	-25	-
Oni (U4 = 0)	33	97	59	50	35	65	80	70	20	85	0	-
	-	-	-	-	**3807**	-	-	-	**18 405**	-	**12 533**	**34 745**
	-23	-87	-33	-20	0	-45	-44	-10	0	-10	0	-
Phc (U5 = 0)	36	84	65	30	95	20	36	120	65	150	0	-
	-	-	-	**5114**	-	**3719**	**1888**	-	-	-	**1554**	**12 275**
	-26	-74	-39	0	-60	0	0	-60	-45	-75	0	-
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: Total cost (Objective value) = NGN 1725033. The costs for each iteration after analysis are indicated in bold.
Ben, Benue; Cal, Calabar; Dummy, dummy variable; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

TABLE 15: Iteration 9.

Supply/Demand names	Aba (V1 = 10)	Cal (V2 = 10)	Uyo (V3 = 26)	Owe (V4 = 26)	Enu (V5 = 35)	Phc (V6 = 20)	Yen (V7 = 36)	Ebo (V8 = 60)	Oni (V9 = 20)	Ben (V10 = 75)	Dummy (V11 = 0)	Supply
Aba (U = 0)	10	64	26	26	59	36	62	75	33	84	0	-
	33 739	-	**10 315**	**5114**	-	-	-	-	-	-	**832**	**50 000**
	0	-54	0	0	-24	-16	-26	-15	-13	-9	0	-
Cal (U2 = 0)	64	10	30	90	85	84	93	80	97	90	0	**17 817**
Enu (U3 = -25)	-	**5888**	-	-	-	-	-	-	-	-	**11 929**	-
	-54	0	-4	-4	-50	-64	-57	-20	-77	-15	0	-
	59	85	79	92	10	95	125	35	35	50	0	**12 475**
	-	-	-	-	**8525**	-	-	**1286**	-	**2664**	-	-
	-74	-100	-78	-91	0	-100	-114	0	-40	0	-25	-
Oni (U4 = 0)	33	97	59	50	35	65	80	70	20	85	0	-
	-	-	-	-	**3807**	-	-	-	**18 405**	-	**12 533**	**34 745**
	-23	-87	-33	-24	0	-45	-44	-10	0	-10	0	-
Phc (U5 = 0)	36	84	65	30	95	20	36	120	65	150	0	-
	-	-	-	-	-	**3719**	**1888**	-	-	-	**6668**	**12 275**
	-26	-74	-39	-4	-60	0	0	-60	-45	-75	0	-
Demand	**33 739**	**5888**	**10 315**	**5114**	**12 332**	**3719**	**1888**	**1286**	**18 405**	**2664**	**31 962**	**-**

Note: Total cost (Objective value) = NGN 1704577. The costs for each iteration after analysis are indicated in bold.
Ben, Benue; Cal, Calabar; Dummy, dummy variable; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

TABLE 16: Inputs from warehouse to distributors.

From	To	Amount shipped	Objective	
			Coefficient	Contribution
Aba	Aba	33 739	10	337 390
	Uyo	10 315	26	268 190
	Owe	5114	26	132 964
	Dummy	832	0	0
Cal	Cal	5888	10	58 880
	Dummy	11 929	0	0
Enu	Enu	8525	10	85 259
	Ebo	1286	35	45 010
	Ben	2664	50	133 200
Oni	Enu	3807	35	133 245
	Oni	18 405	20	368 100
	Dummy	12 533	0	0
Phc	Phc	3719	20	74 380
	Yen	1888	36	67 968
	Dummy	6668	0	0

Ben, Benue; Cal, Calabar; Dummy, dummy variable; Ebo, Ebonyi; Enu, Enugu; Oni, Onitsha; Owe, Owerri; Phc, Port Harcourt; Yen, Yenagoa.

Conclusion

The study explored the transport model of physical distribution of raw materials or finished products from several supply locations to result in minimum (optimal) cost of physical distribution. Management of the product distribution from the factory to several depots and customer locations was examined to arrive at a solution that would make profit for the company and simultaneously enhance the company's cost minimisation approach. The objective of this study was to find the optimal allocation (least cost) of shipments of two manufactured products between depots and places of consumption. The study was deemed necessary because of the high operating costs associated with physical distribution when deliveries are not properly planned and evaluated with consideration to alternative strategies. In contrast, cost can be significantly reduced, resulting in higher profits, with the use of modern techniques to determine the cheapest methods of transporting goods from several origins to several destinations. Cost minimisation is a very useful approach to the solution of transportation problems. The dummy variable that was introduced shows that the company produces more than what the customers can consume and they need to reduce their production. They should also align their production to demand.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

N.O.R. (Federal University of Technology Minna) was the project leader, responsible for experimental and project design and data gathering and analysis. O.V. (Federal University of Technology Minna) performed most of the experiments, U.E.C. (Federal University of Technology Owerri) and U.S.I. (Federal University of Technology Owerri) were responsible for conceptual contributions.

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