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Article

Routing and facility location optimization in a dairy products supply chain

Ovundah King Wofuru-Nyenke*

Department of Mechanical Engineering, Faculty of Engineering, Rivers State University, Port Harcourt, Rivers State, Nigeria

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*Corresponding author
Email address:
ovundah.wofuru-nyenke@ust.edu.ng

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ABSTRACT

Routing and facility location optimization is an important aspect of supply chain management. This is because the problem of determining which facilities within a supply chain echelon should cost-effectively supply products to facilities in the next echelon is usually encountered by supply chain managers and analysts. In this paper, a linear programming model for supply chain routing and facility location optimization has been proposed. The model can be solved using the PuLP optimization library implemented in Python programming language. The model has been applied to a small dairy products supply chain to determine the most cost-effective routes for products in the supply chain. The optimization results proffered the optimal contribution of each factory warehouse to each distribution warehouse in order to satisfy distribution warehouse demand while minimizing costs. The results of the study indicated that the model is efficient in solving the routing and facility location optimization problem usually encountered in supply chain management. Therefore, this study will aid supply chain analysts and managers in determining the most cost-effective route for distributing products between echelons or stages of supply chains under study.

1. Introduction

Optimization of supply chains is a continuous process that supplies chain managers and analysts engage in to achieve a reduction in costs, increase in service levels, as well as increase in profit across entire supply chains. Supply chain optimization usually includes product demand forecasting so as to have an idea of the demand for a particular product by consumers [1, 2]. This is usually followed by manufacturing optimization through various methods to produce the right quantity and quality of products that satisfy customer demand at reduced costs [3-5]. After manufacturing, it is necessary to know the most cost-effective routes to get the manufactured products to consumers in order to satisfy demand. In supply chain management, this process of determining the best route for products that minimize distance, travel time, and transportation cost is known as routing. Routing and facility location optimization are some of the most crucial aspects of supply chain optimization. Therefore, many researchers have proposed models for determining the most cost-effective routes for distributing products within manufacturing supply chains, taking various factors into consideration. However, models that can be used for small and medium-sized supply chains, which do not necessarily have the complexities of larger supply chains, are lacking [6]. Wang et al. [7] proposed a linear programming model for optimizing the downstream oil supply chain taking into consideration the planning of routes of pipelines and demand uncertainty. The objective function of the model comprised of cost of transportation as well as the cost of construction. The model was applied to a real-world oil supply chain, and the results indicated that the model was suitable for distribution and route planning for the downstream oil supply chain. Wong et al. [8] developed a model for truckload utilization, vehicle routing as well as carbon emissions optimization for third-party logistics. The mathematical model was deemed suitable for aiding routing planners to decrease cargo planning time and optimize truckload operations. Routing optimization has also been applied to the medical sector [9], where Bounitsis et al. [10] and Lee et al. [11] applied optimization models for medical oxygen distribution to hospitals, improving the distribution of medical oxygen between oxygen manufacturers and managers in the healthcare sector. Abedi and Zhu [12] proposed an optimization model for improving the distribution in a fish supply chain. The model was applied to a real-world supply chain to improve the distribution planning and delivery of fresh trout fish to the most profitable consumers. The results indicated that the optimized distribution strategy is viable for increasing the total profit of fish farmers compared to the traditional distribution strategy. Becerra et al. [13] proposed an optimization model for handling location, inventory, and transportation decisions in single-product closed-loop supply chains. The objectives of the model included carbon emissions, economic and social costs minimization as well as supply chain social impact maximization. Some researchers have presented models for vehicle routing in a multi-echelon supply chain [14-16]. Giallanza and Puma [14] applied their optimization model to an agri-food supply chain to demonstrate their model's robustness in minimizing total costs and carbon emissions. The results indicated that the model is suitable for determining the best vehicle routing configurations of three-echelon agri-food supply chains. Caramia et al. [17] developed a model for concurrently optimizing facility location, clustering, and routing for waste management in supply chains. The model served to assign the demand to the appropriate facilities while minimizing greenhouse gas emissions in the supply chain. Pilati and Tronconi [18] presented an optimization model for e-commerce platforms, which were consolidating orders and picking up many requests from similar locations. Therefore, the work proposed a multi-objective optimization model for solving the delivery vehicle routing problem of the e-commerce sector. Similarly, Jaigirdar et al. [19] presented a multi-objective optimization model for planning the distribution of perishable goods supply chains. The model served to decrease yearly supply chain cost, the cost of cold storage setup, and enhance the freshness of perishable foods by establishing the optimal distribution channels. Abbaspour et al. [20] developed an integrated optimization model that concurrently solves the queueing, routing, and inventory problems encountered in manufacturing supply chains. The model was applied to a construction material producers' supply chain, and the model was deemed suitable for optimizing routing, delivery time interval as well as inventory replenishment in supply chains. The aim of this study is to propose an efficient routing and facility location optimization model that can be used to determine the most cost-effective routes for products in a supply chain.

The model proposed is a linear programming model that was solved using the PuLP optimization library implemented in Python programming language. The model proves to be efficient in solving the routing and facility location optimization problem usually encountered in optimizing supply chains. The following sections provide the formulation of the model as well as the results of applying the model to a dairy products supply chain.

2. Methodology

This study utilizes various tools and methods for optimizing the routing and facility location of a small dairy products supply chain. The supply chain produces and delivers yoghurt in 50cl and 75cl sizes, and consists of three (3) factory warehouses and eight (8) distribution warehouses (Figure 1). The objective of the problem is to choose the best potential sites and routes for establishing facilities that satisfy demand at the distribution warehouses and also minimize costs at the factory warehouses, subject to various constraints. Therefore, this study proposes a mathematical model for selecting facility sites in order to minimize costs. The factory warehouses have limited capacities for satisfying the demand of the distribution warehouses, therefore, classifying the problem as a capacitated facility location and routing problem. As mentioned earlier, the supply chain consists of three (3) factory warehouses and eight (8) distribution warehouses. The monthly cost of using a factory warehouse, j, is fj. The maximum amount that can be handled monthly by factory warehouse j is Mj. There is also a transportation cost, cij, per unit transported from factory warehouse, j, to distribution warehouse, i. The monthly demand for products is di. These data are shown in Table 1.

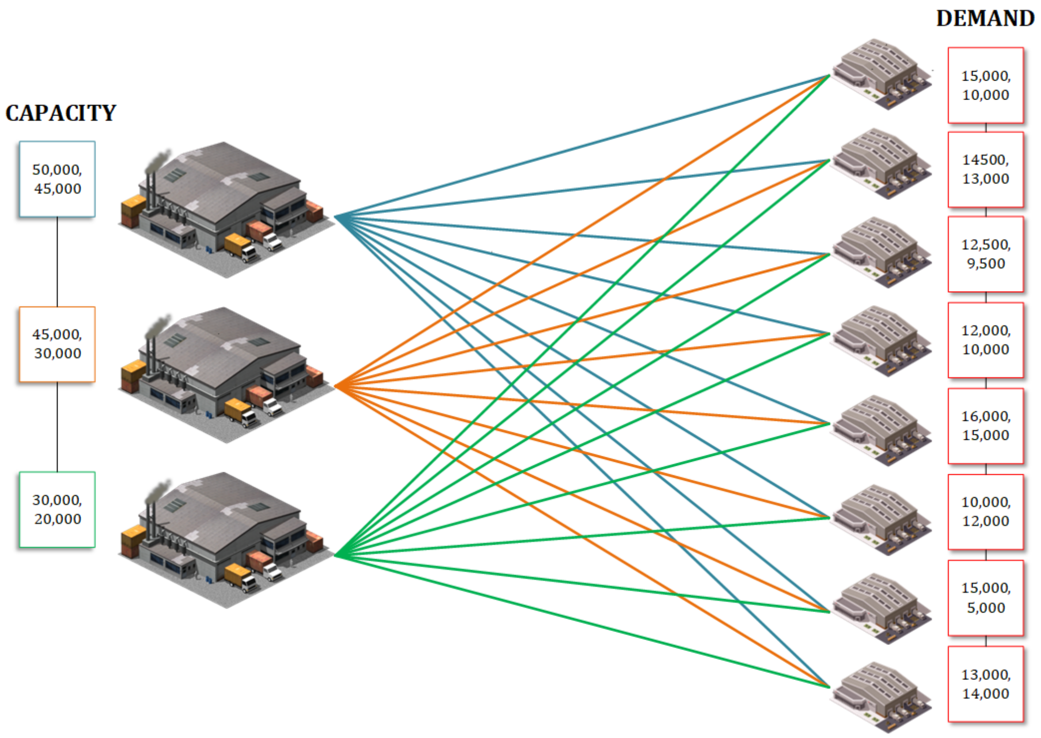

Figure 1. Capacitated facility location and routing optimization problem

Table 1. Routing and facility location data

Distribution Warehouse, i	Monthly demand at distribution warehouse, d_i		50cl product transportation cost per product from j to i (₦)			75cl product transportation cost per product from j to i (₦)		
	50cl demand, d_{i1}	75cl demand, d_{i2}	Factory warehouse 1	Factory warehouse 2	Factory warehouse 3	Factory warehouse 1	Factory warehouse 2	Factory warehouse 3
1	15,000	10,000	80	20	90	85	25	95
2	14,500	13,000	60	60	45	65	60	50
3	12,500	9,500	30	40	50	35	45	55
4	12,000	10,000	70	70	70	75	75	75
5	16,000	15,000	40	80	80	45	85	85
6	10,000	12,000	90	20	20	95	35	25
7	15,000	5,000	20	45	60	25	50	65
8	13,000	14,000	50	55	75	55	60	80

The above problem can be formulated as a mathematical optimization model whose objective is to minimize the sum of transportation costs and factory warehouse usage costs. Consider n distribution warehouses, i = 1, 2, …, n and m factory warehouses, j = 1, 2, …, m. The integer optimization model for the capacitated facility location problem, taking one product at a time, can be specified as follows:

$$\sum_{j=1}^{m} f_j y_j + \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij} x_{ij} \quad (1)$$

$$\sum_{j=1}^{m} x_{ij} = d_i \quad (2)$$

$$\sum_{i=1}^{n} x_{ij} \le M_j y_j \quad (3)$$

$$x_{ij} \le d_i y_j \quad (4)$$

$$x_{ij} \ge 0 \quad (5)$$

$$y_j \in \{0, 1\} \quad (6)$$

where x_{ij} is the amount of product transported from factory warehouse, j, to distribution warehouse, i. Also, y_j is 1 if a factory warehouse is established at location, j, otherwise y_j is 0. The monthly cost of using a factory warehouse, j, is f_j. The maximum amount that can be handled monthly by factory warehouse j is M_j. There is also a transportation cost, c_{ij}, per unit transported from factory warehouse, j, to distribution warehouse, i. The monthly demand for products is d_i.

This mathematical formulation can be solved using the Python programming language through the PuLP optimization library, which is a linear programming modeler.

3. Results and Discussion

The results of the optimization indicate that the three factory warehouses are useful and can be used together to minimize cost of the entire supply chain. The results indicated that the optimal cost of factory warehouse operation and transportation incurred in supplying the dairy products to distribution warehouses is ₦15,292,500 per month, with the 50cl products contributing ₦7,690,000 per month to this cost, and the 75cl products contributing ₦7,602,500 per month to the cost. Figure 2 is a pie chart that shows the approximate percentage contribution of each product to the total monthly cost of factory warehouse operation and the cost of transportation of products to distribution warehouses. From Figure 2, each dairy product handled by the supply chain (50cl and 75cl yoghurt products) contributes approximately 50% to the total cost of factory warehouse operation and the cost of transportation of products to distribution warehouses. Figure 3 is a bar chart that shows the quantity of 50cl yoghurt products each factory warehouse is expected to supply to each distribution warehouse in order to achieve the optimal ₦15,292,500 per month total cost of factory warehouse operation and cost of transportation of products to distribution warehouses. From Figure 3, distribution warehouse 1 is expected to receive 0 units of 50cl product from factory warehouse 1, 15,000 units of 50cl product from factory warehouse 2 and 0 units of 50cl product from factory warehouse 3. Therefore, for cost effectiveness, all of the demand by distribution warehouse 1 will be satisfied by factory warehouse 2. Also, distribution warehouse 2 is expected to receive 0 units, 0 units, and 14,500 units from factory warehouses 1, 2, and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 2 will be satisfied by factory warehouse 3. Distribution warehouse 3 is expected to receive 12,500 units, 0 units, and 0 units from factory warehouses 1, 2, and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 3 will be satisfied by factory warehouse 1. Distribution warehouse 4 is expected to receive 0 units, 12,000 units, and 0 units from factory warehouses 1, 2, and 3, respectively.

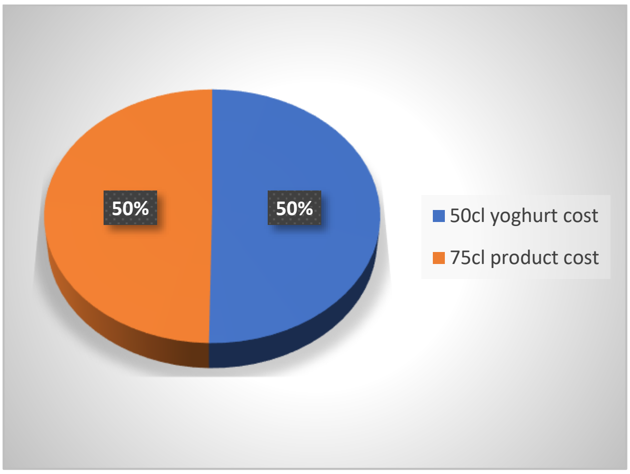

Figure 2. Approximate percentage contribution of each dairy product to the cost of factory warehouse operation and cost of transportation of products to distribution warehouses

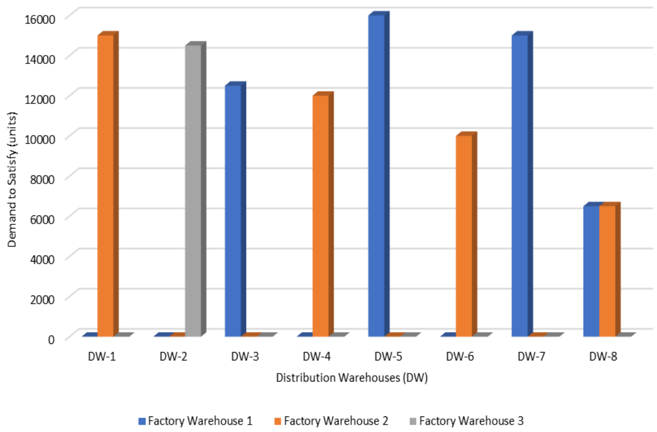

Figure 3. Quantity of 50cl yoghurt products each factory warehouse is expected to supply to each distribution warehouse

Therefore, for cost-effectiveness, all of the demand by distribution warehouse 4 will be satisfied by factory warehouse 2. Distribution warehouse 5 is expected to receive 16,000 units, 0 units, and 0 units from factory warehouses 1,2, and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 5 will be satisfied by factory warehouse 1. Distribution warehouse 6 is expected to receive 0 units, 10,000 units, and 0 units from factory warehouses 1,2 and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 6 will be satisfied by factory warehouse 2. Distribution warehouse 7 is expected to receive 15,000 units, 0 units, and 0 units from factory warehouses 1,2 and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 7 will be satisfied by factory warehouse 1. Finally, distribution warehouse 8 is expected to receive 6,500 units, 6,500 units, and 0 units from factory warehouses 1,2 and 3, respectively. Therefore, for cost-effectiveness, the demand by distribution warehouse 8 will be satisfied by factory warehouse 1 and factory warehouse 2, with each factory warehouse supplying 6,500 units. Figure 4 is a bar chart that shows the quantity of 75cl yoghurt products each factory warehouse is expected to supply to each distribution warehouse in order to achieve the optimal ₦15,292,500 per month total cost of factory warehouse operation and cost of transportation of products to distribution warehouses.

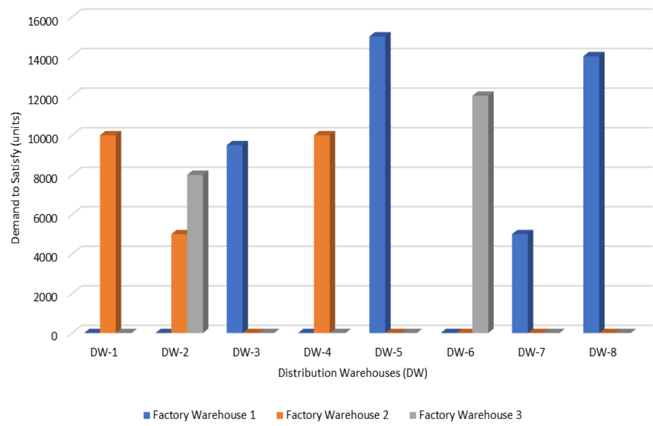

Figure 4. Quantity of 75cl yoghurt products each factory warehouse is expected to supply to each distribution warehouse

From Figure 4, distribution warehouse 1 is expected to receive 0 units of 75cl product from factory warehouse 1, 10,000 units of 75cl product from factory warehouse 2, and 0 units of 75cl product from factory warehouse 3. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 1 will be satisfied by factory warehouse 2. Also, distribution warehouse 2 is expected to receive 0 units, 5,000 units, and 8,000 units from factory warehouses 1, 2, and 3, respectively. Therefore, for cost-effectiveness, the demand by distribution warehouse 2 will be satisfied by factory warehouses 2 and 3, with factory warehouse 2 contributing 5000 units and factory warehouse 3 contributing 8000 units. Distribution warehouse 3 is expected to receive 9,500 units, 0 units, and 0 units from factory warehouses 1, 2, and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 3 will be satisfied by factory warehouse 1. Distribution warehouse 4 is expected to receive 0 units, 10,000 units, and 0 units from factory warehouses 1, 2, and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 4 will be satisfied by factory warehouse 2. Distribution warehouse 5 is expected to receive 15,000 units, 0 units, and 0 units from factory warehouses 1,2 and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 5 will be satisfied by factory warehouse 1. Distribution warehouse 6 is expected to receive

0 units, 0 units and 12,000 units from factory warehouses 1,2 and 3, respectively. Therefore, for cost effectiveness, all of the demand by distribution warehouse 6 will be satisfied by factory warehouse 3. Distribution warehouse 7 is expected to receive 5,000 units, 0 units, and 0 units from factory warehouses 1,2 and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 7 will be satisfied by factory warehouse 1. Finally, distribution warehouse 8 is expected to receive 14,000 units, 0 units, and 0 units from factory warehouses 1,2 and 3, respectively. Therefore, for cost-effectiveness, all of the demand by distribution warehouse 8 will be satisfied by factory warehouse 1.

4. Conclusions

Supply chain managers and analysts are usually faced with the problem of determining the most cost-effective routes for distributing products between echelons or stages of supply chains being analyzed. In this study, the most cost-effective routes for products in a small dairy products supply chain have been determined. The study proposes a model for supply chain routing and facility location optimization, which can be solved using the PuLP optimization library implemented in Python programming language. The model has been applied to a small dairy products supply chain that handles 2 products, 3 factory warehouses, and 8 distribution warehouses. The objective of the model is to minimize the combined costs of utilizing factory warehouses and transporting the products from factory warehouses to distribution warehouses. The results showed that the two products contribute approximately equally to the total monthly supply chain cost of factory warehouse operation and transportation to distribution warehouses. Moreover, the optimization results proffered the optimal contribution of each factory warehouse to each distribution warehouse in order to satisfy distribution warehouse demand while achieving optimal costs. Therefore, this study will aid supply chain analysts and managers in determining the most cost-effective route for distributing products between warehouses of supply chains under study.

Ethical issue

The author is aware of and complies with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

Datasets analyzed during the current study are available and can be given following a reasonable request from the corresponding author.

Conflict of interest

The author declares no potential conflict of interest.

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