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Optimal location selection for a new processing plant using supply chain and distribution network analysis

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ABSTRACT

Selecting an optimal processing plant location is a critical decision in supply chain management, directly affecting operational efficiency, cost-effectiveness, and distribution logistics. This study aims to identify the most suitable location for a new processing plant that sources raw materials from three suppliers and distributes finished products to two distribution points. We employed the Center-of-Gravity method to determine the optimal geographical location and a cost-minimization model to ensure minimal transportation expenses. We analyzed data on supply capacities, demand requirements, transportation costs, and geographical coordinates. The Center-of-Gravity calculations identified an optimal location at coordinates (24.67, 19.50). Further cost-optimization modeling revealed that this location reduces total transportation costs to NGN 80,500.00, yielding lower costs than alternative sites. These findings confirm that an optimally selected plant location significantly lowers logistics costs and enhances supply chain efficiency. This study underscores the effectiveness of integrating quantitative techniques in facility location decisions. To further refine such analyses, future research could incorporate real-time traffic data, infrastructure availability, and environmental factors. These insights offer valuable guidance for industries seeking cost-efficient, strategically positioned processing facilities.

1. Introduction

Plant design encompasses critical business factors such as market demand, site selection, product characteristics, construction and operational expenses, production capabilities, government regulations, climate conditions, and the competitive landscape [1]. The choice of location is a fundamental aspect of industrial engineering, as a careful evaluation before establishing a production facility can lead to optimal material utilization, cost efficiency, improved customer service, broader market reach, and strategic and competitive advantages over rivals [2].

Selecting the ideal facility location is vital because it represents a long-term commitment, where mistakes can be costly and difficult to correct. Moreover, it significantly influences both expenses and revenue generation [3]. Decisions regarding plant location may stem from factors such as shifts in production capacity, expansion or reduction of product lines, changes in distribution costs, or fluctuations in customer demand [4]. Poor location choices can result in issues such as a lack of skilled labor, scarcity of raw materials, inadequate transportation infrastructure, higher operational costs, or even severe organizational disruptions due to political or social factors [5].

A supply chain is defined as a network of organizations, individuals, activities, information, and resources involved in delivering a product or service from suppliers to customers [6]. The core principle of supply chain management (as shown in Fig. 1) is to recognize the interconnectedness within the supply chain and to improve its structure and control by integrating business processes [7]. With increasing environmental awareness, it has become essential to address pollution and sustainability concerns associated with industrial growth within supply chain operations, giving rise to the concept of green supply chain management (GSCM) [8], [9].

Various methodologies, including location-allocation models, the center-of-gravity approach, and linear programming, have been extensively utilized to address facility location optimization and supply chain challenges [10–12]. Recognizing the critical role of strategic plant placement, this study focuses on tackling the issue of selecting the optimal location for a new

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processing plant by integrating supply chain and distribution network analysis [13]. To achieve this, the research adopts a multi-criteria decision-making (MCDM) framework, which incorporates both quantitative and qualitative factors to assess potential sites. MCDM techniques are mathematical models designed to evaluate multiple alternatives against conflicting criteria, enabling the identification of the best possible solution [14–16].

This study reviews research on plant location analysis methods and their applications, proposing a methodology that integrates geographic information systems (GIS), linear programming, and network optimization to assess the impact of location on transportation costs, lead times, and overall supply chain performance [17]. Fig. 2 shows the hierarchical structure of MCDM methods.

In recent years, numerous studies have employed Multi-Criteria Decision-Making (MCDM) models for location selection across industries, including the energy sector [18-20]. For example, Ceballos et al. conducted an empirical comparison of MCDM methods, analyzing over 1,600 randomly generated decision problems to evaluate similarities and differences in ranking outcomes [21]. While the literature extensively applies MCDM, it rarely integrates geospatial optimization tools, such as the center-of-gravity approach, with cost-minimization modeling [22]. Moreover, research addressing facility location for dual-stage distribution networks (supply-to-plant and plant-to-market) in the agro-processing sector—where perishability, cost sensitivity, and infrastructure constraints demand high efficiency—remains limited [23].

This study addresses these gaps by combining spatial analysis with cost-minimization optimization to determine optimal locations for new agro-industrial processing facilities. The center-of-gravity method identifies a candidate central facility location, which is then evaluated using a linear programming model to minimize total transportation costs. This integrated framework, tailored to the agro-industrial context, ensures efficient management of raw material and product flows, critical for economic viability. By applying industry-relevant geolocations and cost data, this paper contributes practically to both academic research and industrial decision-making [24].

In 2020, Žic et al. applied MCDM to supply chain management, focusing on inventory levels, environmental impact, and costs [25]. Their study examined a single-echelon inventory system with policy-based and normally distributed market demand, incorporating factors such as demand fluctuations, service constraints, predefined lead times, and operational downtime. Through 4,000 simulation experiments, they validated their findings.

Although some researchers favor the PROMETHEE technique, both the Analytic Hierarchy Process (AHP) and PROMETHEE have distinct strengths and limitations. Recognizing this, Mousavi et al. developed an integrated decision-making framework combining Delphi, AHP, and PROMETHEE to optimize the use of implicit and explicit information [26]. This approach supports manufacturing industry experts by identifying critical criteria and evaluating alternatives effectively. Similarly, Uygun and Dede evaluated Green Supply Chain Management (GSCM) using integrated fuzzy MCDM techniques [27]. Their performance evaluation model, validated through a case study of four companies, assessed predefined green dimensions and criteria. Ghosh et al. introduced another GSCM framework to evaluate supplier organizations, demonstrating that leading manufacturing organizations provide benchmarks for improving performance [28].

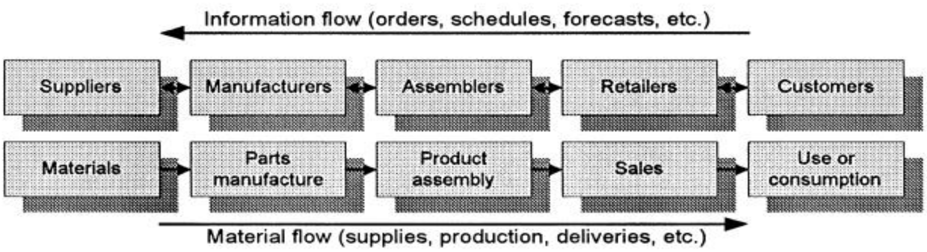

Figure 1: Supply chain generic configuration [6]

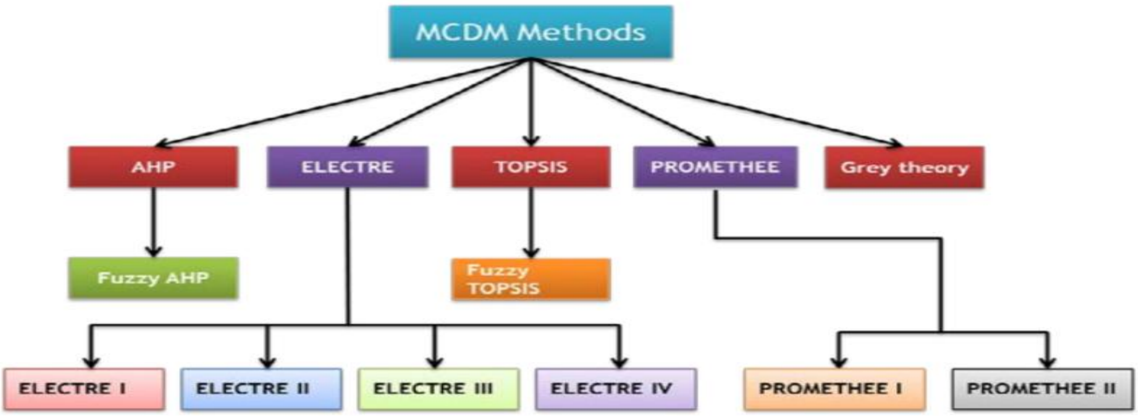

Figure 2. Hierarchical structure of MCDM Methods [11]

Banasik et al.'s review, "Multi-Criteria Decision-Making Approaches for Green Supply Chains," developed a conceptual framework to categorize relevant publications by decision problems, indicators, and MCDM approaches [29]. Their findings highlighted: (1) the emerging but growing application of MCDM in green supply chain design, (2) a focus on production and distribution with limited attention to inventory models incorporating environmental factors, (3) prevalent use of deterministic data, (4) minimal emphasis on waste minimization, and (5) a lack of standardized eco-efficiency indicators. Boutkhoum et al. underscored MCDM's technical and analytical contributions to environmental decision-making, particularly in GSCM [30].

Yazdani et al. advanced the field by introducing a hybrid MCDM method using gray numbers to rank supply chain management contracts in the oil and gas industry, emphasizing the importance of selecting evaluation factors before choosing contracts [31]. Cengiz et al. proposed an MCDM model for selecting suppliers of wall, cladding, and roofing materials, demonstrating the suitability of the Analytic Network Process (ANP) when decision criteria are interdependent [32]. They also introduced a novel MCDM framework to address complex interrelationships among supply chain management attributes [32]. Their empirical findings revealed that flexibility is significantly influenced by process integration, information integration, and strategic alliances for eco-design, with process integration having the greatest impact on innovation-driven competitive advantages.

Overall, literature reviews and expert opinions emphasize that economic, environmental, technical, and socio-political factors must be considered in plant location selection.

2. Material and method

2.1. *Center-of-Gravity method*

The center-of-gravity method is to calculate and determine the weighted average location considering supply and demand quantities. Eqs. (1) and (2) are used to calculate the center-of-gravity

$$x_c = \frac{\sum_{i \in I} x_i \, w_i}{\sum_{i \in I} w_i} \quad (1)$$

$$y_c = \frac{\sum_{i \in I} y_i \, w_i}{\sum_{i \in I} w_i} \quad (2)$$

where x_c and y_c denote the coordinate of the optimal location, I denotes the set of potential location, x_i and y_i denote the coordinate of location i, and w_i denotes the weight of the location i.

2.2. *Cost optimization model*

To validate the center-of-gravity result and determine the most cost-effective location, a linear programming (LP) model was formulated to minimize transportation costs.

Sets and indices

- I Set of supplier location
- J Set of distribution location
- i Index of supplier
- j Index of distributor

Parameters

- c_{ij} Cost per unit distance between supply source i and distribution point j
- s_i The supply capacity of location i
- d_j The demand of location j

Decision variables

- Q_{ij} Quantity transported between location i and j

Minimize

$$\sum_{i \in I} \sum_{j \in J} c_{ij} Q_{ij} \quad (3)$$

subject to

$$\sum_{j \in J} Q_{ij} \le s_i \,, \forall i \quad (4)$$

$$\sum_{i \in I} Q_{ij} \le d_j \,, \forall j \quad (5)$$

Eq. (3) represents the objective function for minimizing total transportation costs. Eq. (4) defines the supply capacity constraint. Eq. (5) specifies the demand constraint.

2.3. *Data collection*

This study collects data from three primary supply sites (S1, S2, and S3) and two distribution points (D1 and D2). The collected parameters include supply capacities at each source (kg per month), demand requirements at each distribution point, transportation costs per unit distance for raw materials and finished products, and the geographical coordinates of supply sources, potential plant locations, and distribution points. The supply and demand values reflect representative figures common in agro-processing industries, particularly in sub-Saharan Africa, based on estimated average monthly material flow volumes.

A linear cost model was used to determine transportation costs per unit distance. The analysis incorporates standard road transportation assumptions for the region, excluding variations in fuel costs, maintenance expenses, and toll fees. Euclidean (straight-line) distances between geographical coordinates were calculated to simplify computational processes and generalize findings. Random geographical coordinates, constrained within realistic boundaries, were selected to support spatial analysis using ArcGIS [20]. This data structure enables replicable methods that can be adapted for subsequent modeling in similar studies.

Table 1.
Supply and demand data

Point	Annotation	X-coordinate	Y-coordinate	Quantity (kg)	X-Weighted	Y-Weighted
Supply	S1	10	20	50	500	1000
	S2	25	30	40	1000	1200
	S3	35	10	60	2100	600
Demand	D1	20	15	70	1400	1050
	D2	30	25	80	2400	2000
Total		-	-	300	7400	5850

Table 2.
Cost optimization data

No	Potential location	Total transportation cost (N)	Feasibility
1	24.67 and 19.50	80,500.00	Optimal
2	20, 18	90,200.00	Suboptimal
3	30, 20	100,100.00	Suboptimal

The researchers utilized Microsoft Excel Solver for center-of-gravity calculations, MATLAB and Python for cost optimization computations, and ArcGIS for spatial visualizations.

3. Results and discussions

3.1. Center-of-gravity calculations

Table 1 provides the data required to calculate the center-of-gravity coordinates for the optimal location of the processing plant. The center-of-gravity method identifies a location that minimizes transportation costs by balancing supply and demand points. Table 1 lists the three supply sources (S1, S2, and S3) and two distribution points (D1 and D2), along with their respective X- and Y-coordinates, which represent the geographical locations of each point. The "Quantity (kg)" column indicates the supply or demand quantity at each point, while the "Weighted-X" and "Weighted-Y" columns show the weighted coordinates, calculated by multiplying the X- and Y-coordinates by the corresponding quantity (weight) at each point.

Table 1 also indicates that the total Weighted-X value is 7,400, and the total Weighted-Y value is 5,850. The total quantity (sum of supply and demand) is 300 kg. Consequently, the center-of-gravity method yields an optimal location at coordinates (24.67, 19.50). These results demonstrate that the center-of-gravity method effectively identifies a location that balances supply and demand points, minimizing total transportation costs. The coordinates (24.67, 19.50) represent the optimal geographical location for the processing plant, considering the distribution of supply sources and demand points.

3.2. Cost optimization results

Table 2 presents the results of the cost optimization model, which evaluates total transportation costs for various potential plant locations to identify the most cost-effective site while ensuring feasibility. The table lists the coordinates of three potential locations for the processing plant, including the optimal location derived from the center-of-gravity method. The "Total Transportation Cost (N)" column indicates the cost associated with each location, and the "Feasibility" column specifies whether the location is optimal or suboptimal based on the cost analysis.

The cost optimization model compares alternative locations, revealing that the optimal location at coordinates (24.67, 19.50) yields the lowest total transportation cost of N80,500.00 (eighty thousand five hundred naira). Suboptimal locations at (20, 18) and (30, 20) incur higher costs of N90,200.00 (ninety thousand two hundred naira) and N100,100.00 (one hundred thousand one hundred naira), respectively. As derived from Eq. (2), the optimal location minimizes total transportation costs at N80,500.00.

The cost optimization model confirms that the center-of-gravity location (24.67, 19.50) is the most cost-effective, resulting in the lowest transportation costs. Alternative locations, although feasible, are suboptimal due to increased distances to supply sources and distribution points, which elevate logistics costs.

These results underscore the importance of selecting a location that balances supply and demand while minimizing transportation costs, a critical factor for operational efficiency and cost-effectiveness. Table 2 validates the optimal location by comparing transportation costs across potential sites, confirming that the center-of-gravity location is the most suitable for the processing plant.

The findings indicate that the ideal location for the processing plant is at (24.67, 19.50), which optimizes supply and demand logistics while minimizing costs. This aligns with previous studies on facility location optimization [11, 25, 28], where the center-of-gravity approach effectively identifies cost-efficient sites. The cost analysis demonstrates that alternative locations result in higher logistics expenses due to greater distances to supply sources and distribution points. Moreover, suboptimal placement could lead to supply chain disruptions, further emphasizing the need for precise location selection [30–32].

The findings highlight the value of quantitative methods, such as the center-of-gravity approach and cost optimization models, in facility location decisions. These methods reduce logistics costs and enhance supply chain efficiency [23]. This study provides a practical methodology for industrial facility siting. However, real-world applications should also consider additional factors, including land costs, regulatory constraints, and environmental impact assessments.

4. Conclusions

This study identifies the optimal location for the processing plant at coordinates (24.67, 19.50), which balances supply and demand logistics while minimizing transportation costs. The center-of-gravity method effectively determines a cost-efficient facility location based on the distribution of supply sources and demand points, and the cost optimization analysis confirms that this location minimizes transportation expenses. This approach enhances operational efficiency by optimizing raw material supply and product distribution.

However, the analysis omits several real-world factors, including land acquisition costs, traffic conditions, road quality, and regulatory requirements. Incorporating land prices could shift the optimal location away from geometric centers, as lower property costs are often found in urban-rural transition areas. Similarly, analyzing traffic flow patterns and road conditions may reveal that shorter routes incur higher costs or longer travel times, affecting total transportation expenses and potentially altering the location decision. These factors were excluded to maintain model simplicity, but their omission highlights limitations in applying the framework to real-world scenarios.

Future research could enhance location decision-making by integrating real-time traffic data, infrastructure development, and environmental impact factors. Combining spatial, economic, and infrastructural considerations through multi-objective optimization methods would provide industrial planners with more robust decision-support systems. This study offers a practical methodology for facility siting, demonstrating the value of center-of-gravity analysis and cost minimization modeling, while underscoring the need to address real-world constraints in future applications.

Declaration statement

All the work in this article is done solely by the author.

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