# Operations research techniques for cost minimization in transportation

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**Abstract:** Efficient distribution of goods from multiple sources to multiple destinations is a central challenge in supply chain management, particularly in developing economies where logistics costs significantly affect profitability and accessibility. This study evaluates the performance of three classical transportation problem methods — the North-West Corner Method (NWCM), the Least Cost Method (LCM), and Vogel's Approximation Method (VAM) — in minimizing total distribution costs. Data were obtained from the 2023 operational records of a Nigerian fertilizer manufacturing company comprising 10 supply outlets and 15 distributors. The transportation problem was formulated as a balanced linear programming model and solved using all three methods, implemented in R. NWCM produced the highest total cost of ₦1,478,625, while LCM yielded ₦813,150. VAM achieved the lowest cost of ₦749,025, saving over ₦700,000 compared to NWCM and approximately ₦64,000 compared to LCM. VAM consistently outperformed the other methods by incorporating penalty costs that guide allocation toward near-optimal routes. The findings underscore the practical importance of method selection in logistics decision-making and recommend VAM for repeated supply chain operations. Future research may explore advanced techniques such as the MODI method for further optimization.

**Keywords:** Transportation Problem; Optimization; Supply-Demand Allocation; Supply Chain Management; Vogel's Approximation Method.

## Introduction

Efficient allocation of resources across supply and demand nodes is a central challenge in operations research, particularly within the domain of transportation problems. The transportation problem seeks to determine the most cost-effective way to distribute products from multiple sources to multiple destinations while satisfying the constraints of supply and demand. Usually, transportation constitutes a significant proportion of total

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logistics cost of an organization. It is desirable to minimize the cost in order to achieve considerable savings for the organization. Previous studies reported that in many industries, distribution costs may account for 20 to 30% of overall production and operational expenses, which makes optimization crucial for competitiveness and profitability (Taha, 2017; Chopra, 2025; Onanaye *et al.*, 2023).

The importance of transportation optimization transcends industries and geographies. In developed economies, transportation models are widely applied in supply chain design, humanitarian logistics, and manufacturing distribution (see Hillier & Lieberman, 2021). However, in developing countries, such as Nigeria, the relevance of transportation optimization is particularly pronounced due to infrastructural challenges, high energy costs, and limited financial resources. Efficient management of transportation systems can reduce wastage, enhance profitability, and improve access to essential goods, especially in agriculture and food supply chains.

Fertilizer distribution plays a pivotal role in supporting agricultural productivity in Nigeria. Fertilizers are essential for increasing crop yields and availability of farm produce, but their distribution costs often inflate market prices, restricting accessibility for micro farmers who form the backbone of the agricultural sector. Addressing inefficiencies in fertilizer transportation can improve both economic and social benefits, reduce the financial burden on farmers and enhance food security.

The transportation problem provides a mathematical framework for minimizing distribution costs by selecting the most efficient allocation strategy. However, the efficiency of the solution depends heavily on the method employed. Classical methods for solving transportation problems include the North-West Corner Method (NWCM), Least Cost Method (LCM), and Vogel's Approximation Method (VAM). Although, the NWCM is simple to apply, it is often inefficient. The LCM improves on the strength of NWCM by considering cost structures, while VAM introduces penalty costs to achieve near-optimal results. Comparing these methods using real data provides actionable insights for managers and policymakers.

This study applies the three classical methods to transportation data extracted from the records of a Nigerian fertilizer company with 10 outlets and 15 distributors. The aim is to evaluate which method yields the most cost-effective solution and to highlight the practical implications of method selection in logistics decision-making. Specifically, the study examines the efficiency of each method, compares cost outcome, and provides recommendations for practical implications.

**Method**
In 1958, W. R. Vogel introduced the Vogel's approximation Method (VAM) as a heuristic approach for finding an initial feasible solution to the transportation problem. It appeared in the literature as a practical improvement over earlier methods like the NWCM and LCM. VAM usually produces an initial solution much closer to the true optimum, thereby reducing the number of iterations needed in optimization. Unlike the Vogel's Approximation Method, the NWCM and LCM cannot be attributed to a single inventor. They emerged as part of the early development of transportation problem algorithms in

Operations Research in the late 1940s and early 1950s, following the seminal works of Hitchcock (1941) **and** Koopmans (1947). The former worked on *the distribution of a product from several sources to numerous localities while the latter* developed and generalized the transportation model.

Ajibade & Babarinde (2013) worked on solution techniques for transportation problems for shipping newspapers from 3 supply centers to 12 demand centers. They observed that VAM yielded a solution closest to the optimum among the techniques considered. Aliu *et al*. (2022) proposed North-East Corner Rule (NECR), South-West Corner Rule (SWCR) and South-East Corner Rule (SECR) and assessed their performances comparatively with the North-West Corner Rule (NWCR), Least Cost Method (LCM) and Vogel's Approximation Method (VAM). They discovered that NWCR and SECR behaved alike. Also NECR and SWCR were similar in behaviour. The diagonal relationships of these pairs of rules could be said to be responsible for the similarities. Researchers such as Korukuglu & Balli (2011), Murugesan & Esakkimmal (2020), Pratihar *et al*. (2021) and Awogbemi *et al*. (2022) investigated methods for achieving optimal solutions to various transportation problems. The present study, involving 10 sources and 15 destinations, is relatively distinct from these previous studies in terms of problem scale.

Transportation problem is a special class of linear programming designed to minimize the total cost of transporting goods while satisfying the requirements of supply and demand. The mathematical formulation of transportation problem is described as follows.
Suppose there are $m$ sources and $n$ destinations, the cost of transporting items from the sources to destinations can be expressed as

$$Minimize\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} \qquad\qquad 1$$

Subject to

$$\sum_{j=1}^{n} x_{ij} = a_i, \quad i = 1,2,\dots,m \qquad\qquad 2$$

$$\sum_{i=1}^{m} x_{ij} = b_j, \quad j = 1,2,\dots,n \qquad\qquad 3$$

$$x_{ij} \geq 0 \qquad\qquad 4$$

Where $c_{ij}$ = cost of transporting one unit from source $i$ to destination $j$, $x_{ij}$ = number of units transported from source $i$ to destination $j$, $a_i$ = supply available at source $i$, and $b_j$ = demand required at destination $j$

When total supply equals total demand, the problem is called a *balanced transportation problem*. In cases where they differ, dummy sources or destinations are added to balance the model.

The transportation problem was formulated mathematically as a linear programming model with the objective of minimizing the total transportation cost. The objective function was expressed as equation (5)

$$Minimize\ Z = \sum_{i=1}^{10} \sum_{j=1}^{15} c_{ij} x_{ij} \qquad\qquad 5$$

where $c_{ij}$ is the cost of transporting one bag from outlet $i$ to distributor $j$, and $x_{ij}$ is the number of bags transported from outlet $i$ to distributor $j$. Substituting actual coefficients from the dataset, the full expanded function becomes

$$Z = 13x_{AI} + 19x_{AII} + 16x_{AIII} + 9x_{AIV} + \cdots + 9x_{JXIV} + 18x_{JXV} \qquad 6$$

With the supply constraints (Equation 7)

$$x_{AI} + x_{AII} + x_{AIII} + \cdots + x_{AXV} = 110$$
$$x_{BI} + x_{BII} + x_{BIII} + \cdots + x_{BXV} = 158$$
$$\vdots$$
$$x_{JI} + x_{JII} + x_{JIII} + \cdots + x_{JXV} = 180 \qquad\qquad 7$$

and the demand constraints (Equation 8)

$$x_{AI} + x_{BI} + x_{CI} + \cdots + x_{JI} = 54$$
$$x_{AII} + x_{BII} + x_{CII} + \cdots + x_{JII} = 64$$
$$\vdots$$
$$x_{AXV} + x_{BXV} + x_{CXV} + \cdots + x_{JXV} = 80 \qquad\qquad 8$$

with             non-negativity             restrictions             (Equation             9)             $x_{ij} \geq$
$0\ \forall\ i,j$                                                                   9.

These constraints ensure that all supply and demand requirements are satisfied.

Three classical solution techniques earlier mentioned were applied. The North-West Corner Method (NWCM) starts allocation from the top-left cell of the cost matrix and proceeds sequentially until all the requirements for supply and demand are met, ignoring cost considerations and often yielding suboptimal results. Least Cost Method (LCM) provides improvement upon NWCM by iteratively assigning shipments to the least-cost cell available until all requirements are satisfied, generally producing a lower total cost. The Vogel's Approximation Method (VAM) further improves allocation by introducing penalties representing opportunity costs for each row and column, leading to near-optimal solutions with relatively simple computations (see Hadley, 1962; Shore, 1970; Ahuja *et al*, 1993; Jalal *et al*., 2017; Hillier & Lieberman, 2021). It is important to note that this study focuses exclusively on obtaining and comparing initial basic feasible solutions (IBFS) generated by each method. The objective is to assess the relative cost performance of the three methods at the IBFS stage, which is a recognised and meaningful basis for comparison in the transportation problem literature.

**Result and Discussion**

The dataset used for this study was obtained from the 2023 operational records of a Nigerian fertilizer manufacturing company, which consisted of ten supply outlets and fifteen distributors. Each distributor had specified demand requirements and each outlet had a given supply level which translated into demand and supply constraints. The unit transportation cost per bag was determined from historical distribution records, incorporating fuel, labor, and handling expenses. This particular transportation problem is a balanced type where total supply equaled total demand. Applying the methods discussed earlier to the fertilizer dataset produced the following total transportation costs:

**Table 1:** North-West Corner Allocation

*Part A: Distributors I – VIII*

| Outlet | I | I | IV | VI | VII | VIII |
|--------|-----|-----|-----|-----|-----|------|
| A | 54 | 56 | — | — | — | — |
| B | — | 8 | 30 | — | — | — |
| C | — | — | 90 | — | — | — |
| D | — | — | — | 32 | — | — |
| E | — | — | — | 88 | 58 | — |
| F | — | — | — | — | 33 | 88 |
| G | — | — | — | — | — | 33 |
| H | — | — | — | — | — | — |
| I | — | — | — | — | — | — |
| J | — | — | — | — | — | — |

*Part B: Distributors IX – XV*

| Outlet | IX | X | XI | XII | XIII | XIV | XV |
|--------|-----|-----|-----|-----|------|-----|-----|
| A | — | — | — | — | — | — | — |
| B | — | — | — | — | — | — | — |
| C | — | — | — | — | — | — | — |
| D | — | — | — | — | — | — | — |
| E | — | — | — | — | — | — | — |
| F | — | — | — | — | — | — | — |
| G | 50 | 46 | — | — | — | — | — |
| H | — | 76 | 121 | — | — | — | — |
| I | — | — | 6 | 104 | 12 | — | — |
| J | — | — | — | — | 52 | 48 | 80 |

The NWCM is used specifically to find basic feasible solution for transportation problems in linear programming. Its algorithm begins at the top-left cell (North-West Corner) of the cost matrix and proceeds procedurally until all the demand and supply requirements are satisfied. Table 1 has shipments allocation from the 10 outlets to the 15 distributors using North-West Corner Method. Table 2 has the shipping plans and associated cost implications across the outlets and distributors as well as total bags shipped and total cost for implementing the plans. All the three techniques considered in this study were implemented in the environment of R statistical packages.

**Table 2:** North-West Corner Shipping Plan and Costs of Shipping

| Outlets | Distributors | Bags Shipped | Cost per Bag (₦) | Total Cost (₦) |
|---|---|---|---|---|
| A | I | 54 | 975 | 52,650 |
| A | II | 56 | 1425 | 79,800 |
| B | II | 8 | 1500 | 12,000 |
| B | III | 120 | 675 | 81,000 |
| B | IV | 30 | 900 | 27,000 |
| C | IV | 90 | 1200 | 108,000 |
| C | V | 40 | 1425 | 57,000 |
| D | V | 61 | 975 | 59,475 |
| D | VI | 32 | 900 | 28,800 |
| E | VI | 88 | 750 | 66,000 |
| E | VII | 58 | 600 | 34,800 |
| F | VII | 33 | 1275 | 42,075 |
| F | VIII | 88 | 1350 | 118,800 |
| G | VIII | 33 | 975 | 32,175 |
| G | IX | 50 | 1350 | 67,500 |
| G | X | 46 | 1050 | 48,300 |
| H | X | 76 | 1425 | 108,300 |
| H | XI | 121 | 1050 | 127,050 |
| I | XI | 6 | 750 | 4,500 |

| | | | | |
|---|---|---|---|---|
| **I** | XII | 104 | 900 | 93,600 |
| **I** | XIII | 12 | 1275 | 15,300 |
| **J** | XIII | 52 | 1425 | 74,100 |
| **J** | XIV | 48 | 675 | 32,400 |
| **J** | XV | 80 | 1350 | 108,000 |
| **TOTAL** | | **1386** | | **1,478,625** |

From Table 2, it can be observed that a total number of 1,386 bags were transported from the company's outlets to the distributors costing ₦1,478,625 in total.

The Table 3 below shows shipments allocation from the 10 outlets to the 15 distributors using Least Cost Method and Table 4 that flows contains the shipping plans, associated cost implications across the outlets and distributors, total bags shipped and total cost for implementing the plans using LCM. Table 4 has it that a total number of 1,386 bags were transported from outlets of the company to the distributors at a total cost of ₦813,150.

**Table 3:** Least Cost Allocation

*Part A: Distributors I – VIII*

| Outlet | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| **A** | — | — | — | — | 41 | — | — | — |
| **B** | — | — | — | — | — | — | — | 40 |
| **C** | — | — | — | — | — | — | 91 | 39 |
| **D** | — | — | — | — | — | — | — | — |
| **E** | — | 64 | — | — | — | — | — | — |
| **F** | 54 | — | — | — | — | — | — | — |
| **G** | — | — | — | 120 | — | — | — | — |
| **H** | — | — | — | — | — | — | — | 40 |
| **I** | — | — | 120 | — | — | — | — | 2 |
| **J** | — | — | — | — | 60 | 120 | — | — |

*Part B: Distributors IX – XV*

| Outlet | IX | X | XI | XII | XIII | XIV | XV |
|---|---|---|---|---|---|---|---|
| **A** | — | 21 | — | — | — | 48 | — |
| **B** | — | — | 118 | — | — | — | — |
| **C** | — | — | — | — | — | — | — |
| **D** | — | — | — | 93 | — | — | — |
| **E** | — | 18 | — | — | 64 | — | — |
| **F** | — | 67 | — | — | — | — | — |
| **G** | — | — | 9 | — | — | — | — |
| **H** | 50 | 16 | — | 11 | — | — | 80 |
| **I** | — | — | — | — | — | — | — |
| **J** | — | — | — | — | — | — | — |

**Table 4:** Least Cost Shipping Plan

| Outlets | Distributors | Bags Shipped | Cost per Bag (₦) | Total Cost (₦) |
|---|---|---|---|---|
| F | I | 54 | 375 | 20,250 |
| E | II | 64 | 825 | 52,800 |
| I | III | 120 | 450 | 54,000 |
| G | IV | 120 | 375 | 45,000 |
| A | V | 41 | 750 | 30,750 |
| J | V | 60 | 600 | 36,000 |
| J | VI | 120 | 375 | 45,000 |
| C | VII | 91 | 375 | 34,125 |
| B | VIII | 40 | 600 | 24,000 |
| C | VIII | 39 | 750 | 29,250 |
| H | VIII | 40 | 825 | 33,000 |
| I | VIII | 2 | 525 | 1,050 |
| H | IX | 50 | 1,500 | 75,000 |
| A | X | 21 | 1,275 | 26,775 |
| E | X | 18 | 825 | 14,850 |
| F | X | 67 | 750 | 50,250 |
| H | X | 16 | 1,425 | 22,800 |
| B | XI | 118 | 525 | 61,950 |
| G | XI | 9 | 450 | 4,050 |

| D | XII | 93 | 375 | 34,875 |
|---|---|---|---|---|
| H | XII | 11 | 525 | 5,775 |
| E | XIII | 64 | 375 | 24,000 |
| A | XIV | 48 | 825 | 39,600 |
| H | XV | 80 | 600 | 48,000 |
| **TOTAL** | | **1386** | | **813,150** |

**Table 5:** Vogel Approximation Allocation

*Part A: Distributors I – VIII*

| Outlet | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| A | — | — | — | — | 70 | — | — | — |
| B | — | — | 25 | — | — | — | — | 121 |
| C | 39 | — | — | — | — | — | 91 | — |
| D | — | — | — | — | — | — | — | — |
| E | — | 64 | — | — | — | — | — | — |
| F | 15 | — | — | 106 | — | — | — | — |
| G | — | — | — | 14 | — | — | — | — |
| H | — | — | 23 | — | — | — | — | — |
| I | — | — | 72 | — | — | — | — | — |
| J | — | — | — | — | 31 | 120 | — | — |

*Part B: Distributors IX – XV*

| Outlet | IX | X | XI | XII | XIII | XIV | XV |
|---|---|---|---|---|---|---|---|
| A | — | — | — | — | — | 40 | — |
| B | — | — | 12 | — | — | — | — |
| C | — | — | — | — | — | — | — |
| D | — | 93 | — | — | — | — | — |
| E | — | — | — | — | 64 | — | 18 |
| F | — | — | — | — | — | — | — |
| G | — | — | 115 | — | — | — | — |
| H | — | — | — | 104 | — | 8 | 62 |
| I | 50 | — | — | — | — | — | — |
| J | — | 29 | — | — | — | — | — |

**Table 6:** Vogel Shipping Plan

| Outlets | Distributors | Bags Shipped | Cost per Bag (₦) | Total Cost (₦) |
|---|---|---|---|---|
| C | I | 39 | 525 | 20,475 |
| F | I | 15 | 375 | 5,625 |

| | | | | |
|---|---|---|---|---|
| **E** | II | 64 | 825 | 52,800 |
| **B** | III | 25 | 675 | 16,875 |
| **H** | III | 23 | 975 | 22,425 |
| **I** | III | 72 | 450 | 32,400 |
| **F** | IV | 106 | 450 | 47,700 |
| **G** | IV | 14 | 375 | 5,250 |
| **A** | V | 70 | 750 | 52,500 |
| **J** | V | 31 | 600 | 18,600 |
| **J** | VI | 120 | 375 | 45,000 |
| **C** | VII | 91 | 375 | 34,125 |
| **B** | VIII | 121 | 600 | 72,600 |
| **I** | IX | 50 | 525 | 26,250 |
| **D** | X | 93 | 525 | 48,825 |
| **J** | X | 29 | 675 | 19,575 |
| **B** | XI | 12 | 525 | 6,300 |
| **G** | XI | 115 | 450 | 51,750 |
| **H** | XII | 104 | 525 | 54,600 |
| **E** | XIII | 64 | 375 | 24,000 |
| **A** | XIV | 40 | 825 | 33,000 |
| **H** | XIV | 8 | 1,125 | 9,000 |
| **E** | XV | 18 | 675 | 12,150 |
| **H** | XV | 62 | 600 | 37,200 |

| | | |
|---|---|---|
| **T O T A L** | **1386** | **749, 025** |

Table 5 contains the shipments allocation from the company's 10 outlets to the 15 distributors using Vogel Approximation Method (VAM). Table 6 reports that a total number of 1,386 bags were shipped from the outlets of the company to the distributors at a total cost of ₦749, 025.

**Table 7:** Comparison of the Three Total Transportation Costs

| Method | Total Transportation Cost (₦) |
|---|---|
| **NWCM** | 1,478,625 |
| **LCM** | 813,150 |
| **VAM** | 749,025 |

**Figure 1: Comparison of Total Transportation Costs by Method (Initial Basic Feasible Solutions)**
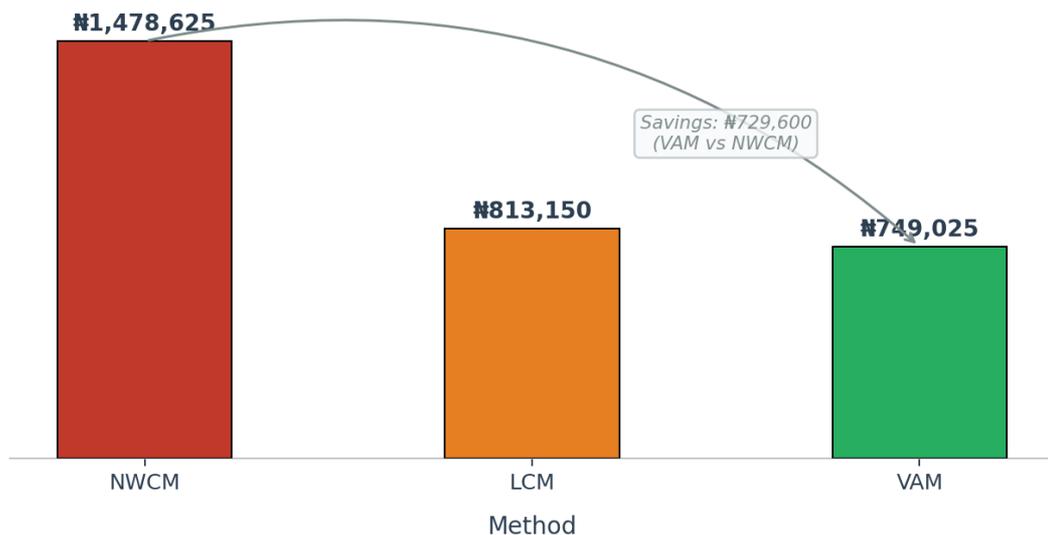


The results in Table 7 show a clear cost advantage of VAM over the other methods which is in agreement with some findings in previous studies that VAM often yields solutions very close to the optimum (see Balakrishnan, 1990; Ajibade & Babarinde, 2013; Hillier & Lieberman, 2021; Aliyu *et al.*, 2022; Onanaye *et al.*, 2023).

The results from this study highlight the importance of selecting appropriate allocation methods for logistics optimization. It should be noted that the cost figures reported represent initial basic feasible solutions (IBFS); optimality testing using procedures such as the MODI method or the Stepping Stone method was not carried out, as the scope of this study is limited to comparing the IBFS generated by each method. Within this scope, the North-West Corner Method (NWCM), while computationally straightforward, produced

the highest cost, underscoring its inefficiency for cost-minimization problems. This outcome is theoretically expected: NWCM allocates resources based solely on positional order in the cost matrix, with no regard for the actual unit transportation costs. As a result, it frequently assigns large shipment quantities to high-cost routes, as evidenced in Table 2 where Outlet A was allocated entirely to Distributors I and II regardless of cost. The Least Cost Method (LCM) significantly reduced transportation costs but still did not achieve the lowest possible allocation cost. This is in agreement with the findings of Chopra (2025). They submitted that cost-focused heuristics must account for global opportunity costs to be effective. Although LCM improves upon NWCM by selecting the cell with the lowest unit cost at each step, it remains a greedy algorithm that does not consider the broader cost consequences of early allocations. This can lead to suboptimal outcomes when cheap cells are exhausted early, forcing subsequent allocations into more expensive routes.

The Vogel's Approximation Method produced the most cost-efficient solution, saving over ₦700,000 compared to NWCM and about ₦64,000 in comparison with LCM. The theoretical superiority of VAM over NWCM and LCM is rooted in its use of penalty costs. For each row and column, VAM computes the difference between the two lowest unit transportation costs — the "penalty" for not selecting the cheapest available route. By prioritising the row or column with the highest penalty, VAM ensures that the most costly missed opportunities are avoided first, producing allocations that are globally more efficient rather than locally optimal. This is illustrated in the VAM allocation pattern (Table 5), where shipments are more widely distributed across cost-effective routes, in contrast to the diagonal concentration observed in the NWCM allocation (Table 1). For instance, VAM correctly assigns Outlet C to Distributor I (at ₦525 per bag) and Outlet F to Distributor I (at ₦375 per bag), routes that NWCM entirely ignores. These cost reductions have practical significance in real-world fertilizer distribution from the outlets of the company to her distribution points. The challenges of rising fuel costs, poor road infrastructure, and high logistics expenses faced by the company can be ameliorated using the right technique. The savings from adopting VAM could be reinvested to improve delivery networks, enhance service reliability, or reduce fertilizer prices for farmers, thereby contributing to food security and economic efficiency.

Findings from this work are consistent with literature emphasizing the effectiveness of VAM as a heuristic for near-optimal solutions (Balakrishnan, 1990; Shore, 1970; Hillier & Lieberman, 2021). From a practical standpoint, the choice of transportation method has direct managerial implications. In supply chains where distribution decisions are made frequently and at scale — such as fertilizer delivery to multiple regional distributors — even marginal per-cycle savings compound significantly over time. The use of VAM in such settings therefore represents not just an academic preference but a measurable operational advantage. The study, therefore, supports the integration of transportation models into decision-making processes for industrial logistics, reinforcing their relevance in achieving cost-efficient operations in supply chains.

## Conclusion
This study analyzed fertilizer distribution data from a Nigerian company using three classical transportation problem methods — NWCM, LCM, and VAM. The analysis was confined to the initial basic feasible solution (IBFS) stage; no optimality test was applied,

and the comparison is therefore among the initial allocations produced by each method. Within this scope, the results confirmed that NWCM, though easy to implement, is not cost-efficient. LCM provided better outcomes by considering transportation costs, but its result was not close to the optimal solution. VAM produced the most efficient allocation because it outperformed other methods. Hence, the study concludes that Vogel's Approximation Method is the most suitable heuristic for minimizing transportation costs in fertilizer distribution. Managers and policymakers in supply chain management are encouraged to prioritize VAM when seeking efficient and practical allocation strategies. It is recommended that logistic companies should adopt cost-minimization models such as VAM to optimize their distribution systems, stakeholders in policymaking arena should support capacity building in operations research techniques to enhance logistics planning in agriculture as well as other sectors. Future research could explore advanced optimization techniques like modified distribution (MODI) method or computational algorithms to evaluate their comparative efficiencies with VAM.

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