



# Transportation Models for Cost Minimization in Distribution Logistics

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## Abstract

Transportation planning is a central operations research problem because organizations must allocate limited supply across multiple destinations while controlling the cost of movement. This paper reviews the role of classical transportation models and initial basic feasible solution methods in distribution cost minimization, with particular attention to the Northwest Corner Method (NWC), Least Cost Method (LCM), Row Minima Method (RMM), and Vogel's Approximation Method (VAM). A focused review of selected peer-reviewed literature is combined with a case study of MAISANGO Cement Nigeria Plc. The studies considered here indicate that transportation problems have developed from classical deterministic allocation models toward broader logistics and supply-chain formulations that incorporate multiple objectives, uncertainty, larger networks, and more advanced computational approaches. Within the classical methods, the literature consistently treats NWC, LCM and VAM as procedures for generating an initial basic feasible solution, rather than as guaranteed optimality methods. The MAISANGO case provides a concrete comparison: all four methods ultimately reach the reported optimal transportation cost of NGN 145,140, while their initial solutions and reported iteration requirements differ substantially. VAM begins at NGN 145,380 and reaches the reported optimum in two iterations. The case therefore shows why these classical methods remain useful, both for understanding transportation models and for handling relatively straightforward distribution decisions and their limitations when real distribution systems become dynamic, uncertain, capacity-constrained, or multi-objective. The paper concludes by identifying directions for extending classical transportation models toward more realistic logistics decision-making.

**Keywords:** operations research; transportation problem; linear programming; Vogel's Approximation Method; Northwest Corner Method; logistics; distribution; cost minimization; supply chain

## 1. Introduction

Operations Research (OR) applies mathematical and analytical methods to decision problems involving limited resources. Transportation models are among its most recognizable applications because they translate a practical distribution problem into a structured optimization model. A typical transportation problem determines how much of a homogeneous product should be shipped from several supply points to several demand points while satisfying supply and demand requirements at minimum total transportation cost.

The classical transportation model remains relevant because the underlying decision appears in many settings: manufacturing distribution, warehouse replenishment, retail networks, humanitarian logistics, and supply-chain planning. At the same time, modern transportation research has expanded beyond the basic deterministic model. Reviews of the field discuss extensions involving different objectives, constraints, algorithms, uncertainty, and increasingly complex distribution networks.

The discussion follows two connected aims. It first brings together selected work on transportation models and initial feasible solution methods. It then uses the MAISANGO Cement Nigeria Plc case reported by Abdullahi et al. (2020) to show how these ideas work in an actual distribution setting. The case is retained because it provides a transparent numerical example through which the practical meaning of the transportation model can be demonstrated.

## 2. Review Scope and Approach

This study uses a focused narrative review. It is not presented as a systematic review or meta-analysis. Sources were selected for direct relevance to transportation problems, transportation solution methods, mathematical programming in supply-chain transport planning, and review studies that identify methodological or application trends. The sources range from foundational work on VAM and classical transportation procedures through recent reviews published in 2023 and 2025.

The review is organized around four questions: (1) how is the classical transportation problem formulated; (2) what role do initial basic feasible solution methods play; (3) what does the literature suggest about the comparative usefulness of classical methods; and (4) what limitations and research directions emerge when the basic model is applied to real distribution systems?

| Literature stream             | Representative source     | Purpose in this review                                               |
|-------------------------------|---------------------------|----------------------------------------------------------------------|
| Classical VAM                 | Shore (1970)              | Explains the logic and role of VAM as an initial-solution procedure. |
| Classical method comparison   | Rafī & Islam (2020)       | Compares standard transportation solution methods.                   |
| Transportation review         | Nursafwah et al. (2023)   | Reviews transportation methods and their applications.               |
| Transportation review         | Malacký & Madleňák (2023) | Maps transportation problem types, algorithms and applications.      |
| Broader transportation review | Zhang & Xie (2025)        | Reviews classical and newer transportation solution approaches.      |
| Supply-chain transport review | Mula et al. (2010)        | Connects transportation modelling to wider supply-chain planning.    |
| Case application              | Abdullahi et al. (2020)   | Provides the MAISANGO dataset and case results used here.            |

### 3. Literature Review

#### 3.1 The transportation problem as an optimization model

The transportation problem is a structured linear programming problem in which sources have available supply, destinations have required demand, and each source-destination pair has an associated unit transportation cost. The decision is the quantity assigned to each route. In the balanced case, total supply equals total demand. The objective is to minimize the sum of route cost multiplied by route quantity.

The continued importance of this formulation is reflected in recent literature reviews. Malacký and Madleňák (2023) describe transportation problems as a classical OR problem while reviewing different problem forms, algorithms, objectives and application areas. Zhang and Xie (2025) similarly review the development of transportation research from tabular methods such as NWC, minimum-cost methods and VAM toward broader solution approaches and applications. These reviews suggest that the basic model remains a foundation even as practical transportation systems become more complex.

#### 3.2 Initial basic feasible solution methods

A key distinction in the literature is between generating an initial basic feasible solution and proving optimality. NWC, LCM, RMM and VAM are used to construct an initial feasible allocation. An optimality procedure is then required if the initial allocation is not already optimal. This distinction is important because a method that produces a low-cost initial solution is not automatically a method that guarantees the global optimum.

| Method           | Basic logic                                                                                        | Main characteristic                                                              |
|------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Northwest Corner | Allocate from the top-left feasible cell and continue through the tableau.                         | Simple; ignores unit costs when making the initial allocation.                   |
| Least Cost       | Allocate as much as possible to the currently lowest-cost cell.                                    | Uses route cost directly when constructing the initial solution.                 |
| Row Minima       | For each row, allocate to its lowest-cost feasible cell.                                           | Uses local row-level cost information.                                           |
| VAM              | Calculate row/column penalties from the two lowest costs and allocate through the largest penalty. | Attempts to account for the opportunity cost of not selecting the cheapest cell. |

Shore (1970) describes VAM as a shortcut for the initial stage of the transportation method. Importantly, the paper does not present VAM as a universal guarantee of optimality. Instead, its appeal is that it often produces a strong starting solution with comparatively little effort. That distinction is important when reading the MAISANGO results.

#### 3.3 What comparative studies suggest

Comparative studies do not establish that one initial-solution method is universally superior for every transportation problem. Rafi and Islam (2020), for example, compare standard transportation procedures and describe VAM as producing a better starting result in their comparison, while NWC is presented as the simplest approach. Nursafwah, Matondang and Ishak (2023), reviewing 24 international studies from 2014-2022, report continued use of VAM and MODI alongside modified and improved methods. Their review also identifies the development of variants such as Improved VAM, indicating that researchers continue to modify classical procedures rather than abandoning them.

The broader literature places these classical methods within a much larger optimization landscape. Mula et al. (2010) reviewed mathematical programming models for supply-chain production and transport planning and classified studies by supply-chain structure, decision level, modelling approach, purpose, limitations, novelty and

application. This shows that transportation decisions increasingly interact with production, inventory, information sharing and other supply-chain decisions rather than existing as isolated allocation problems.

Recent reviews reinforce the same direction. Malacký and Madleňák (2023) discuss applications across logistics, supply-chain management and other domains, while Zhang and Xie (2025) review both classical tabular methods and broader solution approaches. Taken together, the literature indicates a progression from solving a fixed cost-allocation table toward designing models that better represent the uncertainty, scale and competing objectives of real distribution systems.

### 3.4 Literature synthesis and research gap

Taken together, the studies point to four recurring themes. First, the classical transportation model remains a useful baseline because it is transparent, mathematically tractable and easy to interpret. Second, the quality of the initial feasible solution matters because it affects the amount of improvement required before optimality is established. Third, researchers increasingly develop modified or extended methods when the basic assumptions become restrictive. Fourth, supply-chain research increasingly treats transportation as part of an integrated planning system rather than a standalone cost table.

One clear gap is the distance between the simplicity of the classical model and the conditions faced by many real distribution systems. A basic deterministic model assumes known supply, known demand and fixed route costs. In practice, these values can change with fuel prices, road conditions, vehicle capacity, delivery schedules, demand fluctuations and route availability. The literature points toward these extensions, but the classical model remains useful as the starting point against which more complex approaches can be understood.

## 4. MAISANGO Cement Case Study

Abdullahi et al. (2020) examine cement distribution by MAISANGO Cement Nigeria Plc from four depots to five towns in Lagos State. The case uses supply and demand data reported from the company's marketing department and a complete transportation-cost matrix. Total supply and total demand are both 5,100 bags, so the problem is balanced and does not require a dummy source or destination. The original project reproduces these data and uses them as the basis for the mathematical formulation.

| Depot  | Ikeja | Ajagunle | Apapa | Idi-Araba | Agege | Supply |
|--------|-------|----------|-------|-----------|-------|--------|
| A      | 150   | 200      | 180   | 370       | 200   | 1,100  |
| B      | 210   | 120      | 400   | 300       | 190   | 1,220  |
| C      | 250   | 250      | 300   | 100       | 50    | 950    |
| D      | 400   | 400      | 100   | 480       | 450   | 1,830  |
| Demand | 1,010 | 970      | 980   | 1,250     | 890   | 5,100  |

The original project identifies the operational difficulty as route-specific transportation cost, with poor road conditions affecting some routes. There are 20 possible depot-destination routes, so a feasible decision must consider the entire allocation rather than selecting the cheapest route independently. This is exactly the type of allocation trade-off for which the transportation model is designed.

### 4.1 Mathematical formulation

Let  $x_{ij}$  denote the number of cement bags transported from depot  $i$  to destination  $j$ , and let  $c_{ij}$  denote the cost per bag on that route. The model minimizes total transportation cost:

$$\text{Minimize } Z = \sum_i \sum_j c_{ij} x_{ij}$$

subject to the four depot supply constraints, five destination demand constraints, and  $x_{ij} \geq 0$ . Because the problem is balanced, each depot's full supply is allocated and each destination's full demand is satisfied. The original project contains the complete expanded objective and all constraints.

## 4.2 Transportation cost structure

| Depot / Destination | Ikeja | Ajagunle | Apapa | Idi-Araba | Agege |
|---------------------|-------|----------|-------|-----------|-------|
| A                   | 68    | 36       | 26    | 31        | 62    |
| B                   | 35    | 72       | 36    | 28        | 54    |
| C                   | 40    | 55       | 41    | 30        | 28    |
| D                   | 25    | 35       | 40    | 80        | 34    |

Each entry is the reported cost of transporting one bag on the corresponding route. The model therefore does not simply select the cheapest cell in the table. It must combine routes so that all supply and demand conditions are satisfied simultaneously. The original formulation explicitly identifies this as the central allocation decision.

## 5. Comparative Solution Results

The MAISANGO study compares four methods for generating an initial basic feasible solution and then applies an optimality test. The reported results show substantial differences in initial solution cost but convergence to the same final optimal cost.

| Method              | Initial feasible cost (NGN) | Iterations to reported optimum | Reported optimal cost (NGN) |
|---------------------|-----------------------------|--------------------------------|-----------------------------|
| Northwest Corner    | 288,520                     | 9                              | 145,140                     |
| Vogel Approximation | 145,380                     | 2                              | 145,140                     |
| Least Cost          | 160,750                     | 3                              | 145,140                     |
| Row Minima          | 146,760                     | 4                              | 145,140                     |

The comparison shows that the choice of starting method affects the initial cost and the amount of improvement required. VAM's initial solution is only NGN 240 above the reported optimum, whereas the Northwest Corner starting solution is substantially higher. All four methods nevertheless reach the same reported final cost after optimality testing. These figures are taken directly from the project and the cited MAISANGO study.

The study also reports that transportation expenditure falls from NGN 217,150 without the optimization approach to NGN 145,140 under the reported optimized solution, a reported saving of NGN 72,010. This is a case-specific result and should not be generalized as a guaranteed saving for other firms or networks.

### 5.1 Interpretation in light of the literature

The MAISANGO case is consistent with the role assigned to VAM in the classical literature: it produces a low-cost initial allocation and reduces the amount of subsequent improvement needed. Shore (1970) explains why VAM can be effective as an initial procedure, while comparative literature continues to evaluate VAM against NWC, LCM and modified approaches. At the same time, the MAISANGO result should be interpreted as evidence for this particular dataset rather than proof that VAM is always the best transportation method.

The fact that all four methods reach the same reported optimum also illustrates an important methodological point. Initial-solution methods and optimality procedures serve different purposes. A method can be valuable because it gives a strong starting point even when the final optimum is determined by a later test.

## 6. Critical Analysis

### 6.1 Strengths

- The case uses a complete four-depot by five-destination transportation structure, making the allocation problem explicit and reproducible.
- The model connects operational quantities, route-specific costs and mathematical constraints in one coherent formulation.

- Four classical initial-solution methods are compared on the same dataset, allowing differences in starting cost and iteration requirements to be observed.
- The reported optimality result provides a consistency check because all four approaches converge to the same reported final cost.
- The case has clear managerial interpretation because transportation cost is linked directly to distribution allocation.

## 6.2 Limitations

The first limitation is the deterministic nature of the model. Supply, demand and route costs are treated as fixed values, although actual logistics conditions may vary. The second is that the objective is limited to transportation cost. Delivery time, vehicle capacity, fuel consumption, service levels and environmental effects are not included in the formulation. These are also among the extensions identified in the original project.

A further limitation concerns the literature basis of the original project. It centred heavily on one selected case paper. The upgraded manuscript addresses this by placing the MAISANGO case within a broader set of transportation and supply-chain studies. This makes the contribution more appropriate for a review-oriented paper, while still preserving the original case analysis.

There is also a source-level numerical inconsistency in the original MAISANGO paper: the detailed Least Cost calculation and Table 8 report NGN 160,750, while another sentence reports NGN 146,750. The present manuscript retains NGN 160,750 because it is the value supported by the detailed calculation and the table. The original project already identified this discrepancy.

## 7. Implications and Future Research

The literature and the MAISANGO case both suggest that classical transportation models still have a useful place as baseline decision tools, particularly where data are stable and the primary objective is cost minimization. Their main advantage is transparency: managers can see the supply limits, destination requirements, route costs and resulting allocations directly.

There are several practical ways in which this baseline can be extended. First, dynamic transportation costs could be introduced so that fuel prices, congestion or changing road conditions affect route costs. Second, uncertain or time-varying demand and supply could be modelled. Third, the model could incorporate vehicle capacities and delivery-time requirements. Fourth, multi-objective formulations could balance cost against service quality, emissions or delivery time. Finally, larger problems can be solved using computer-based optimization so that the model remains practical as the number of sources, destinations and constraints increases.

These extensions are consistent with the direction of the wider literature, which increasingly connects transportation planning with integrated supply-chain models, modified algorithms and more complex decision environments. The MAISANGO case is better understood as a transparent classical benchmark from which more advanced models can be developed.

## 8. Conclusion

Transportation models provide a structured way to convert a distribution problem into a measurable optimization problem. The studies considered here show that classical methods such as NWC, LCM, RMM and VAM remain important for generating feasible solutions, while later research has expanded transportation modelling toward broader logistics and supply-chain applications.

The MAISANGO Cement case demonstrates the practical value of this framework. Four depots must supply five destinations, with 5,100 bags of total supply exactly matching total demand. The reported optimal transportation cost is NGN 145,140, while VAM produces an initial solution of NGN 145,380 and reaches the reported optimum

in two iterations. The result illustrates why the quality of an initial solution matters, while also showing that the final optimum is established through an optimality procedure rather than by the initial heuristic alone.

For future applications, the central challenge is to preserve the transparency of the classical transportation model while incorporating the uncertainty and competing objectives of modern logistics. This provides a natural research path from simple cost-minimization models toward dynamic, multi-objective and integrated transportation optimization.

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