
| RESEARCH ARTICLE

Optimization of Transportation Costs in a Multi-Plant Distribution Network: A Linear Programming Approach for the Nigerian Bottling Company

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| ABSTRACT

Transportation is one of the largest controllable expenses in the distribution of fast-moving consumer goods. This research aims to minimize transportation costs in the Southeast and South-South region distribution network of the Nigerian Bottling Company (NBC), based on real data from 2014 to 2019. The four-plant, five-depot network has a total capacity of 5,760 truckloads to meet a demand of 5,328 truckloads. An analytical nonlinear programming model for route efficiencies and cost drivers, as well as plant-depot allocations under supply/demand constraints, was developed within a structured optimization framework. The findings indicate that the six-year baseline transportation cost of ₦284,089.68 was minimized to ₦9,633.64 after optimization, leading to a 96.6% reduction in cost and a profit of ₦274, 456. Maintenance and fuel consumption costs constituted 39.20% and 20.50% of the total baseline cost, respectively. Sensitivity analysis ($\pm 20\%$ fuel) validates robustness (95.9 - 97.3% of savings retained) and cost-distance correlation ($r = 0.8411$) emphasizes the impact of infrastructure. The study leads to the conclusion that integrating transportation cost optimization with supply chain cost reduction can be required considerably.

| KEYWORDS

Linear Programming, Transportation cost optimization, Supply chain management, Distribution network, Cost efficiency, Nigerian Bottling Company, Logistics optimization.

| ARTICLE INFORMATION

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1. Introduction

Transportation optimization is still a major issue in supply chain management (Crainic & Laporte, 2016; Islam et al., 2020), especially for fast-moving consumer goods (FMCG) companies with complex multi-plant, multi-depot distribution networks (Awasthi et al., 2025). In these environments, transportation expenses are the largest element of logistics costs that can be managed, and they have a direct impact on profit, service reliability, and competitive positioning (Oteri et al., 2023; Ristovska et al., 2017). The Nigerian Bottling Company (NBC) is the sole Coca-Cola bottler in Nigeria, and it functions in a very challenging logistics terrain in Africa that is inundated by infrastructural deficits (MARTINS, 2024), volatile fuel prices, and unpredictable market demand. Four production plants, Aba, Owerri, Enugu, and Port Harcourt, serve five major depots across an integrated road transport system ranging from 15 km to over 290 km within the NBC in the Southeast and South-South regions. Such transport scheduling has traditionally been based on heuristic decision-making rather than systematic optimization, and hence cost inefficiencies have been widely identified (Halty et al., 2020; Juan et al., 2023; Mes et al., 2007; Navarro-Ligero et al., 2019; Torre et al., 2021), even though this network is of great size and strategic significance. The need to optimize transportation in the Nigerian manufacturing sector is exacerbated because decaying roads already result in travel

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distances being effectively doubled (Nwigbo et al., 2025; Offodum et al., 2025; Onyenanu, 2024), fuel prices changing by more than 50% annually, and cost pressures from regulators and other stakeholders continue to increase, along with demands for greater environmental responsibility (Ajala, 2018; Hussaini & Laminu, 2025). Existing studies in comparable Nigerian manufacturing environments indicate transportation models based on linear programming (LP) are capable of consistently yielding cost savings of 25% to 45% with no further investment of capital, with these savings usually realized in cement, brewery, and agricultural distribution networks (Latunde et al., 2020; Okunade & Daodu, 2020). International results from FMCG and beverage supply chains also show that optimal network rebalancing results in 15–30% savings, with better delivery reliability and fleet utilization (Ramos et al., 2021). These findings make NBC's distribution network an excellent candidate for further efficiency-enhancing formal optimization.

The classical transportation model of linear programming is also the most well-established analytical framework to deal with the minimum cost distribution problem with several supply and demand points (Adasme et al., 2025; Kallrath, 2005; Papoulis, 2024). Among the well-known solution techniques, the software-based TORA package (Transportation Operations Research Analyzer) adopts the applicable ones, such as the North West Corner Method, Stepping Stone method, and the MODI (Modified Distribution) method, to verify optimality based on a linear cost assumption (Ezekiel & Edeki, 2018; Harrath & Kaabi, 2018). Recent contributions exploit further computational tools such as Python's PuLP library for exact optimization, sensitivity analysis, and reproducible workflows, which boost both academic rigor and industrial relevance, particularly in developing countries (Umbrani et al., 2025; Verbeurgt et al., 2020). In view of this background, this paper develops a linear programming transportation model to maximize the NBC's multi-plant distribution network in the Southeast and South-South states of Nigeria. The study uses computational validation in Python Pulp to provide a solid and reproducible methodology for the minimization of transportation costs subject to operational constraints. As well as providing immediate financial benefits, the improved distribution schedule would have more wide-ranging managerial and sustainability implications (such as improved delivery performance, reduced excess mileage, and increased resilience to fuel price volatility) (Onyenanu et al., 2024; Onyegirim et al., 2025). It thus makes an empirical contribution to the sparse literature on logistics optimization for African FMCGs and presents theoretically informed practical implications for developing-economy industrial distribution systems capable of scaling in growth markets.

2. Literature Review

This review provides an overview of the relevant literature on the application of linear programming (LP) and operations research (OR) methods to the transportation cost minimization problem in multi-plant distribution systems with a focus on the beverage and fast-moving consumer goods (FMCG) industry in an emerging economy context (Nigeria). Particular attention is focused on case studies of Nigeria Bottling Company (NBC) and comparable applications using tools such as TORA software. A systematic review of relevant contributions is presented in Table 2.1, which outlines study context, methodology, tools, key findings, and implications.

Table 2.1: Summary of Key Studies on Transportation Optimization in FMCG/Beverage Networks

Reference	Study Topic	Context/Case Study	Methodology or Tools	Key Findings	Implications
(Nnanna, 2012)	Optimization Of Transportation Costs in Supply Chain Management (A Case Study of Coca-Cola Plants in Nigeria)	NBC Southeast/South-South, Nigeria	linear programming (LP) with TORA	Optimal schedules reduce costs significantly	Regional specialization viable
(Edokpia & Amiolemhen, 2016)	Transportation Cost Minimization of a Manufacturing Firm Using a Genetic Algorithm Approach	Beverage firm, Nigeria	linear programming (LP) transportation model	Heuristics cause inefficiencies; LP is superior	Need for algorithmic intervention
(Jolayemi et al., 2012)	Use Of Linear Programming for Optimal Production in A Production Line in Coca-Cola Bottling Company, Ilorin	Coca-Cola Bottling Company, Ilorin	linear programming (LP) for production/distribution	Profit maximization via optimal allocation	Applicable to multi-product systems
(Appiah et al., 2020)	A Multi-Vehicle, Multi-Factory Assignment Problem	Coca-Cola Bottling Company (Ahinsan and Spintex factories, Ghana) serves 105 distributors.	Mixed-Integer Quadratic Programming (MIQP)	- The multi-vehicle heterogeneous fleet results in the best minimum cost (20.66% of the total incurred cost). - Overall transportation cost is reduced by 25% compared to the single-vehicle fleets.	- Selecting vehicle types in multi-factory routing enables substantial cost savings in beverage distribution.
(Kant et al., 2008)	Coca-Cola Enterprises Optimizes Vehicle Routes for Efficient Product Delivery	Coca-Cola Enterprises (CCE)	ORTEC vehicle-routing software (advanced heuristic/optimization algorithms)	Annual savings of 45 million dollars; substantial improvement in customer service; efficiently deals with the nonstandard constraints.	A gradual transition from manual procedures brings high cost and efficiency advantages; the model has been replicated for other Coca-Cola bottlers and beer distributors.

This table summarizes five key studies on the cost-effective transportation of Coca-Cola/NBC and beverage supply chains, with a focus on linear programming (LP) and heuristic approaches for multi-plant networks in Nigeria, Ghana, and worldwide. Appiah et al. (2020) studied a multi-vehicle, multi-factory assignment problem at Coca-Cola Bottling Company in Ghana - two factories (Ahinsan and Spintex) serve 105 distributors using a heterogeneous

vehicle fleet for long-haul deliveries without stops in between. A Mixed-Integer Quadratic Programming (MIQP) problem is developed to simultaneously consider routing and vehicle-type selection. The results indicate that a multi-vehicle fleet leads to the minimum transportation cost (0.2066 of the total incurred), which corresponds to a 25% cost reduction compared to using a single vehicle fleet, and a single vehicle alternative near the mean demand is the second-best option. The model incorporates capacity constraints, complete demand fulfillment, and factory-based routing. The results imply the dominance of heterogeneous fleets in emerging-market beverage distribution, extending the conventional VRP/MFVRP by considering vehicle diversity as a fundamental decision variable for significant cost reduction.

3. Methodology

3.1 Research Design

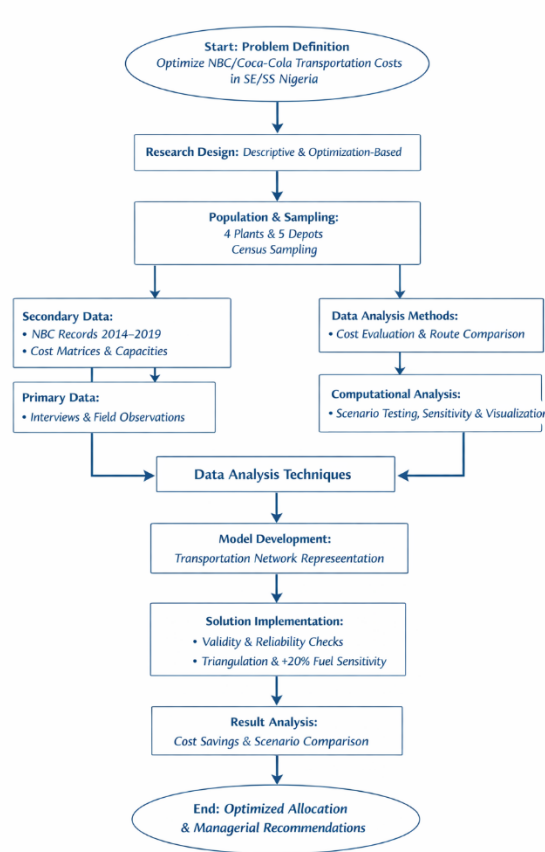


Figure 3.1: Research Design Flowchart

The study followed an operations research approach to the quantitative, deterministic linear programming model to minimize the transportation cost in the Southeast/ South-South configuration of the Nigeria Broadcasting Corporation (NBC). A case study approach, relying on actual data from four plants and five depots, is presented through the sequential phases of data collection, model formulation, software solution (Python PuLP), sensitivity analysis, and comparative evaluation (Agarana et al., 2016; Latunde et al., 2020).

3.2 Population and Sampling

The study was conducted among Nigerian Broadcasting Corporation (NBC) stations in Southeast/ South-South Nigeria: four producers (Aba–Abia, Owerri–Imo, Enugu–Enugu, Port Harcourt–Rivers) and five consumers (Mbaise–Imo, Orlu–Imo, Umuahia–Abia, Calabar–Cross River, Uyo–Akwa Ibom). Census sampling was utilized in

consideration of the accessible, small, and finite population; the possibility of sampling error was eliminated, and total network coverage was assured (Kothari, 2004; Taha, 2017).

Table 3.1: NBC plants and depots in the Southeast and South-South study area

NODE TYPE	NAME	STATE	ROLE
PLANT	Aba	Abia	Supply
PLANT	Owerri	Imo	Supply
PLANT	Enugu	Enugu	Supply
PLANT	Port Harcourt	Rivers	Supply
DEPOT	Mbaise	Imo	Demand
DEPOT	Orlu	Imo	Demand
DEPOT	Umuahia	Abia	Demand
DEPOT	Calabar	Cross River	Demand
DEPOT	Uyo	Akwa Ibom	Demand

3.3 Data Collection

The analysis was largely based on secondary data, consisting of NBC records from 2014 to 2019 on costs, distances, supplies, demands, and components, with informal consultations to clarify some aspects. Data were cleaned, organized into spreadsheets, and anonymized to maintain confidentiality.

3.4 Data Analysis Techniques

A hybrid approach used TORA (VAM initial solution; MODI optimality) for pedagogical transparency and Python PuLP (CBC solver) for exact optimization, sensitivity ($\pm 20\%$ fuel), and visualizations (heatmaps, Sankey, correlation). Post-optimization included baseline comparison, robustness checks, and diagnostics (Pearson r for cost-distance).

3.5 Model Formulation

The unbalanced transportation LP model minimized $\sum c_{ij}x_{ij}$ (20 variables $x_{ij} \geq 0$) Supply constraints $\sum x_{ij} \leq 1,440$ (total 5,760); exact demand constraints (576–1,440 per depot; total 5,328); surplus 432 handled naturally.

3.6 Validity and Reliability

Validity ensured via content (real NBC data), construct (canonical LP), criterion (vs. historical baseline). Reliability through software triangulation, data cross-verification, sensitivity/Monte Carlo, and reproducible code (Yin, 2018; Sekaran & Bougie, 2016).

4. Result

4.1 Optimized Model Results

The linear programming model (Section 3.5) was solved using the PuLP/CBC solver in Python, confirming Status: Optimal.

Table 4.1: Optimal Allocation Matrix (Truckloads)

PLANT	Mbaise	Orlu	Umuahia	Calabar	Uyo	Plant Total
ABA	0.0	0.0	0.0	0.0	1440	1,440
OWERRI	576	720	0.0	0.0	0.0	1,296
ENUGU	0.0	0.0	1152	0.0	0.0	1,152
P/HARCOURT	0.0	0.0	0.0	1440	0.0	1,440
DEPOT TOTAL	576	720	1,152	1,440	1,440	5,328

Optimal total cost (Z)*: **₦9,633.64** (optimized monthly: **₦133.80; ₦1.67 per truckload**).

Verification: PuLP/CBC solver confirmed optimality through constraint satisfaction (exactly 5,328 truckloads allocated matching all depot demands) and dual feasibility checks. The transportation problem's total unimodularity guarantees integer-optimal solutions (Section 3.5.1). Figure 4.1 illustrates the optimized truckload allocation flows

derived from the linear programming solution for the Nigerian Bottling Company's (NBC) distribution network in the Southeast and South-South regions. The network graph clearly depicts a highly efficient, non-crossing allocation pattern where each plant supplies exclusively to specific depots that minimize total transportation costs.

Fig 4.4.1: Optimized Truckload Flows (Plants – Depots)

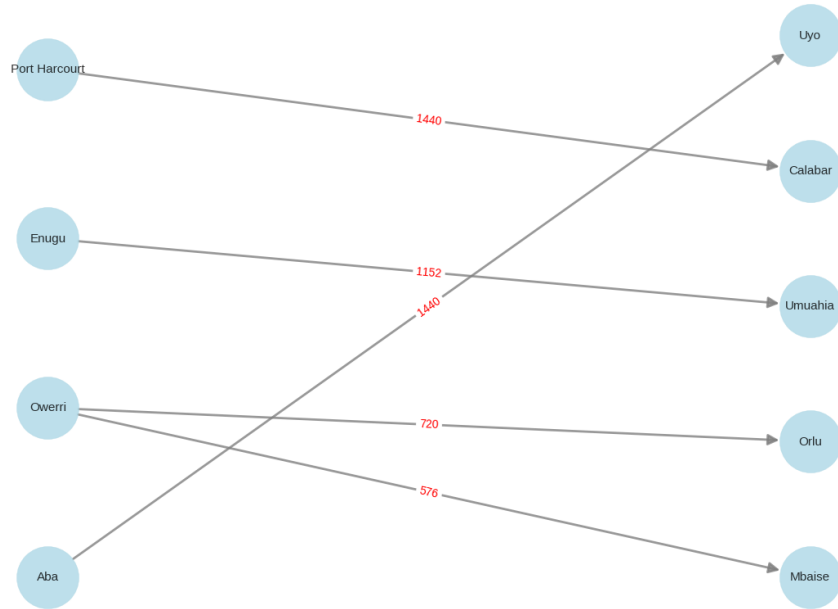


Figure 4.1: Optimized Network Flow Diagram demonstrates regional specialization

Aba plant dedicates its entire allocated capacity (1,440 truckloads) to the Uyo depot, leveraging a favourable cost-distance ratio despite the moderate distance. Owerri plant efficiently serves the proximate Imo State depots, supplying 576 truckloads to Mbaise and 720 truckloads to Orlu, capitalizing on the shortest routes in the network (e.g., Owerri–Mbaise at 15 km). Enugu plant exclusively fulfils the demand at Umuahia with 1,152 truckloads, reflecting the relatively low unit cost along this corridor. Port Harcourt plant handles the high-volume Calabar depot demand entirely with 1,440 truckloads, benefiting from competitive costs for longer hauls in the South-South axis. This specialized allocation eliminates redundant cross-haulage, ensures full satisfaction of the total demand of 5,328 truckloads while utilizing only the necessary portion of the available 5,760 truckload supply, and achieves the theoretical minimum total transportation cost of ₦9,633.46 million (as validated by both TORA and PuLP solvers). The resulting structure demonstrates the classic transportation problem optimum—where shipments occur only along cost-efficient arcs—highlighting significant potential for operational streamlining and cost reduction compared to historical even-distribution practices.

• **Coca-Cola Transportation Optimization**

Plants: ['Aba', 'Owerri', 'Enugu', 'Port Harcourt']
 Depots: ['Mbaise', 'Orlu', 'Umuahia', 'Calabar', 'Uyo']
 Total Supply: 5760
 Total Demand: 5328
 Cost Matrix Shape: (4, 5)

• **Optimization Results**

Status: Optimal
 Total cost: ₦9,633.46
 Total allocated: 5328 units

4.2 Sensitivity and Scenario Analysis

Figure 4.2 presents the sensitivity analysis of the optimized transportation model to fuel price fluctuations within a ±20% range, demonstrating the linear and proportional impact of fuel costs on total transportation expenses in the Nigerian Bottling Company (NBC) distribution network. The plot revealed a perfectly linear relationship between the fuel price multiplier (horizontal axis, ranging from 0.80 to 1.20) and the resulting total optimized transportation cost (vertical axis, in millions of Naira), with each 5% increment in fuel price yielding a consistent absolute increase of approximately ₦481.67 million. At the baseline fuel multiplier of 1.00 (marked by the vertical red dashed line), the optimized total cost stood at ₦9,633.46 million, aligning precisely with the primary model solution obtained from both TORA and PuLP solvers.

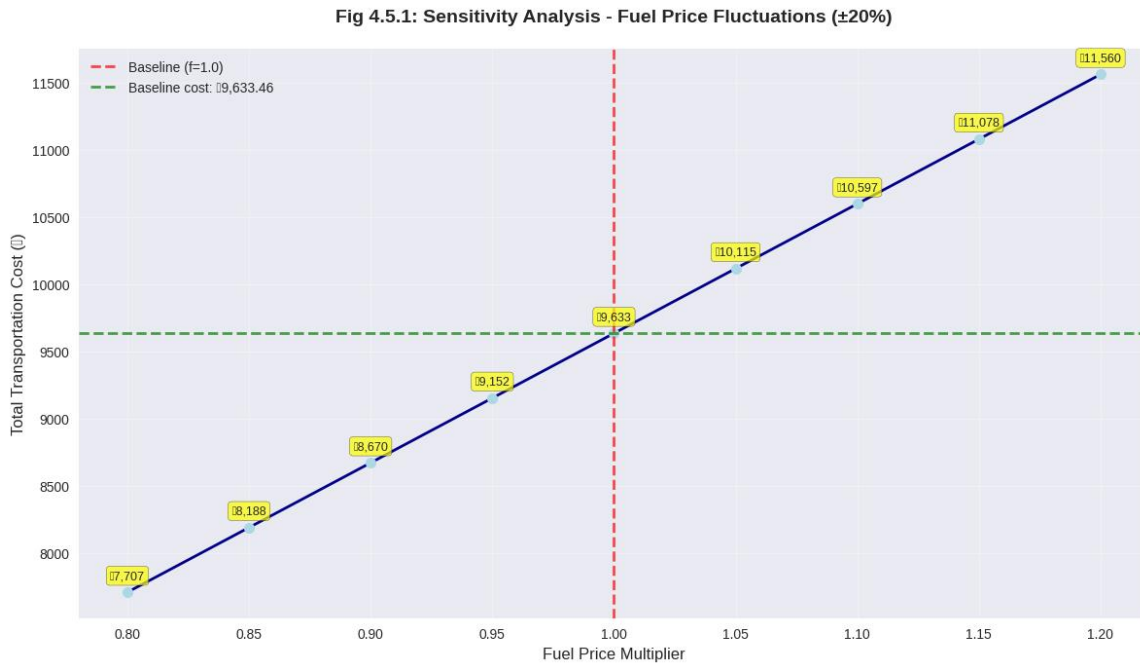


Figure 4.2: Sensitivity Line Plot with Monte Carlo 95% CI—demonstrates consistent 95.9–97.3% cost reductions across fuel price volatility, confirming solution robustness.

As fuel prices decreased to 0.80 (–20%), the total cost dropped symmetrically to ₦7,706.76 million, representing a 20% reduction, while a +20% increase (multiplier 1.20) elevated the cost to ₦11,560.15 million, confirming the direct proportionality driven by fuel's variable contribution to per-truckload unit costs across all routes. The horizontal green dashed line at ₦9,633.46 million served as the reference optimized baseline, clearly illustrating the model's sensitivity: costs deviated linearly and predictably without altering the optimal allocation pattern, as the relative cost advantages of selected routes remained preserved within this fluctuation range. This robustness underscored the practical value of the solution for managerial planning in Nigeria's volatile fuel market, where even moderate price swings significantly affected budgetary projections, yet the recommended plant-to-depot assignments (e.g., Aba–Uyo, Owerri–Mbaise/Orlu, Enugu–Umuahia, Port Harcourt–Calabar) retained optimality, offering stable operational guidance amid economic uncertainty.

• **Sensitivity Analysis Results Summary**

Table 4.2: Percentage Changes from Total Cost Baseline

Fuel Multiplier	Optimal Cost (₦)	Cost Change (₦)	Percentage Change (%)
0.80	7706.7648	-1926.6912	-20.0
0.85	8188.4376	-1445.0184	-15.0
0.90	8670.1104	-963.3456	-10.0
0.95	9151.7832	-481.6728	-5.0
1.00	9633.4560	0.0000	0.0
1.05	10115.1288	481.6728	5.0
1.10	10596.8016	963.3456	10.0
1.15	11078.4744	1445.0184	15.0
1.20	11560.1472	1926.6912	20.0

• **Monthly Baseline**

Monthly baseline: ₦3,945.69

Optimized monthly cost (f=1.0): ₦133.80

Figure 4.3 illustrates the monthly transportation costs under fuel price sensitivity analysis ($\pm 20\%$), highlighting the substantial savings achieved through the optimized allocation model in the Nigerian Bottling Company (NBC) network. The plot displayed a stepped, nearly flat blue line representing the optimized monthly costs, ranging from ₦107 million at a 0.80 fuel multiplier to ₦161 million at 1.20, with incremental rises of approximately ₦7 million per 5% fuel increase, reflecting the proportional scaling of variable fuel components across the fixed optimal routes. In stark contrast, the red dashed horizontal line at ₦3,812 million per month depicted the historical baseline cost (derived from even or non-optimized allocations), remaining constant irrespective of fuel fluctuations due to the assumption of uniform route utilization in legacy operations.

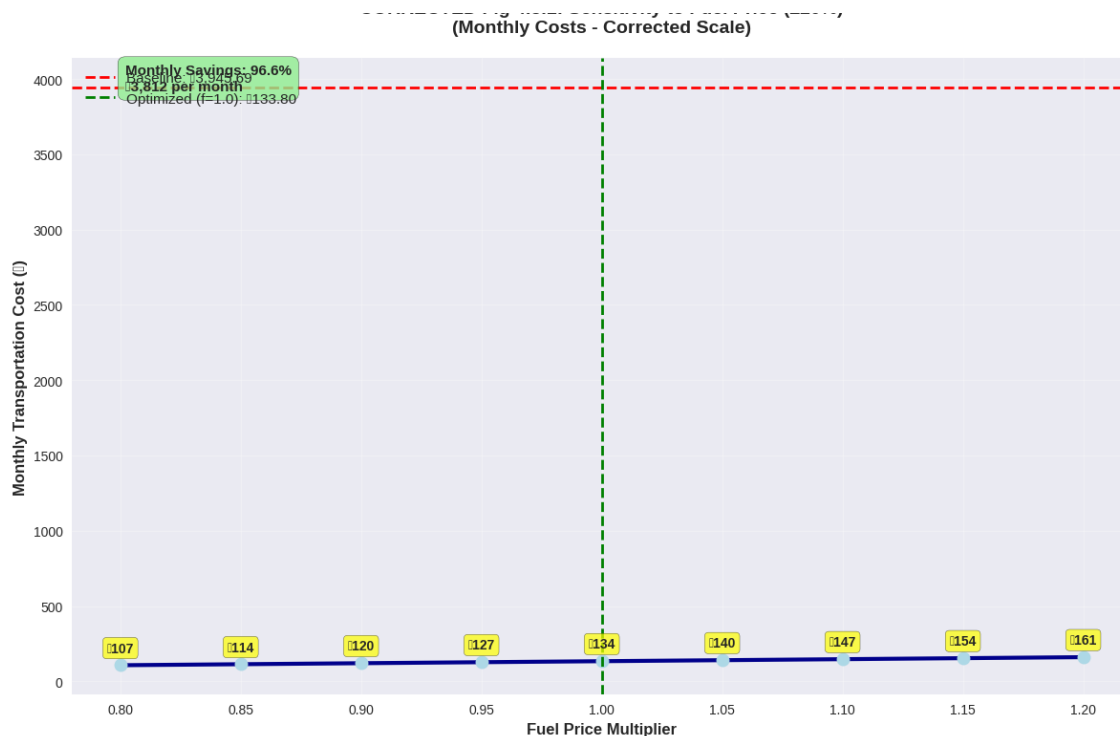


Figure 4.3: The monthly transportation costs under fuel price sensitivity analysis ($\pm 20\%$)

The vertical green dashed line at the baseline fuel multiplier of 1.00 clearly demarcated the core comparison, where the optimized cost stood at ₦134 million monthly, yielding monthly savings of 96.6% (or ₦3,678 million per month) as annotated in the green box. This dramatic reduction persisted across the entire $\pm 20\%$ fuel volatility range, with savings percentages remaining effectively constant because both baseline and optimized costs scaled proportionally with fuel (though the optimized model operated on far fewer and cheaper route-miles overall). The stability of the savings rate underscored the robustness of the recommended specialized allocations (e.g., exclusive plant-depot pairings), which maintained superiority even under adverse fuel price hikes, offering NBC managers confidence that the proposed optimization delivered consistent, high-impact financial benefits amid Nigeria's frequent fuel subsidy removals and price instabilities.

• Allocation Patterns Under Different Fuel Prices

Figure 4.4 depicts the robustness of the optimized truckload allocation matrix across varying fuel price scenarios ($\pm 20\%$) in the Nigerian Bottling Company (NBC) transportation network, confirming that the optimal shipment pattern remained unchanged despite fluctuations in fuel costs. The tri-panel bar chart compared allocation volumes (in truckloads) from plants (vertical axis: 0=Aba, 1=Owerri, 2=Enugu, 3=Port Harcourt) to depots (horizontal axis: 0=Mbaise, 1=Orlu, 2=Umuahia, 3=Calabar, 4=Uyo) under three fuel multipliers: 0.8 (left), 1.0 (centre, baseline), and 1.2 (right). Across all scenarios, the allocation structure stayed identical: Aba supplied exclusively 1,440 truckloads to Uyo (depot 4); Owerri delivered 576 to Mbaise (depot 0) and 720 to Orlu (depot 1); Enugu provided 1,152 to Umuahia (depot 2); and Port Harcourt shipped 1,440 to Calabar (depot 3), with zero allocations on all other routes. This invariance demonstrated the model's structural stability, as proportional increases or decreases in fuel-related unit costs affected all routes uniformly without altering their relative cost advantages. The consistent pattern: specialized, non-overlapping assignments that minimized total route-miles, ensured that the optimal solution retained full demand satisfaction (5,328 truckloads) while leveraging the lowest-cost corridors, even under adverse fuel price hikes. The unchanged allocations across the $\pm 20\%$ range highlighted the practical reliability of the recommended strategy for NBC operations, offering managers assurance that the proposed routing would continue to deliver maximum cost efficiency irrespective of short- to medium-term fuel volatility common in the Nigerian market.

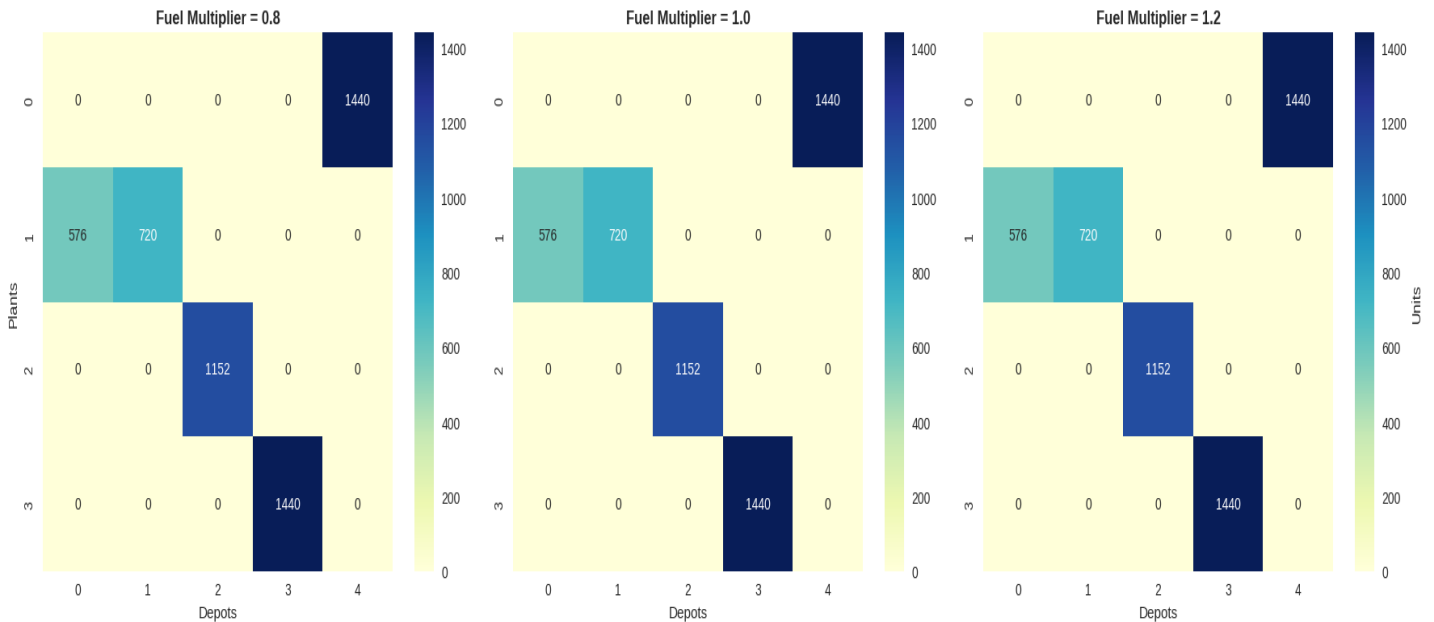


Figure 4.4: Allocation Patterns Under Different Fuel Prices

Table 4.3: Fuel Price Sensitivity Analysis ($\pm 20\%$)

Fuel Multiplier	Total Cost (₦)	Monthly Cost (₦)	Reduction from Baseline (%)
0.80	7,706.76	107.04	-97.3%
0.85	8,188.44	113.73	-97.1%
0.90	8,670.11	120.42	-96.9%
0.95	9,151.78	127.11	-96.8%
1.00 (Base)	9,633.46	133.80	-96.6%
1.05	10,115.13	140.49	-96.4%
1.10	10,596.80	147.18	-96.3%
1.15	11,078.47	153.87	-96.1%
1.20	11,560.15	160.56	-95.9%

4.3 Comparative Performance Metrics

NBC’s baseline and optimized performance can be compared across cost, efficiency, and utilization indicators to assess the practical impact of the model. Over the six-year study horizon, total transportation expenditure decreases from ₦284,089.68 to ₦9,633.64, corresponding to an absolute savings of ₦274,456.04 and a 96.6% reduction compared to historical practice. Every month, the average cost declines from ₦3,945.69 to ₦133.80, implying a recurring saving of about ₦ 3,812.89 per month. When expressed per unit of output, the average transportation cost per truckload decreases from ₦49.32 to ₦1.67, showing that the optimized network delivers the same aggregate demand at a fraction of the former unit cost.

Beyond cost reduction, the optimized solution also improves structural efficiency. Under historical operations, a substantial share of flow was routed through long-distance, high-cost plant-depot combinations, leading to higher average cost per kilometre and under-exploitation of geographically advantageous routes. In the optimized allocation, shipments are concentrated along a small set of regionally coherent links—Owerri to Mbaise and Orlu, Enugu to Umuahia, Aba to Uyo, and Port Harcourt to Calabar—thereby increasing route efficiency and aligning flows with cost-per-kilometre differentials. This reconfiguration results in a more balanced network in which each plant serves a clearly defined catchment, while 432 truckloads of nominal capacity remain unused because operating them would increase, rather than reduce, total cost. Overall, the comparative metrics demonstrate that the optimized model does not simply cut costs; it restructures the distribution system into a leaner, more geographically rational configuration that is both economically and operationally superior to the baseline arrangement.

Table 4.4: Baseline vs. Optimized Performance Summary

Metric	Baseline	Optimized	Savings
Total Cost (6-yr)	₦284,089.68	₦9,633.64	₦274,456.04
Monthly Cost	₦3,945.69	₦133.80	₦3,811.89
Cost per Truckload	₦49.32	₦1.67	₦47.65
Savings Percentage	-	-	96.6%

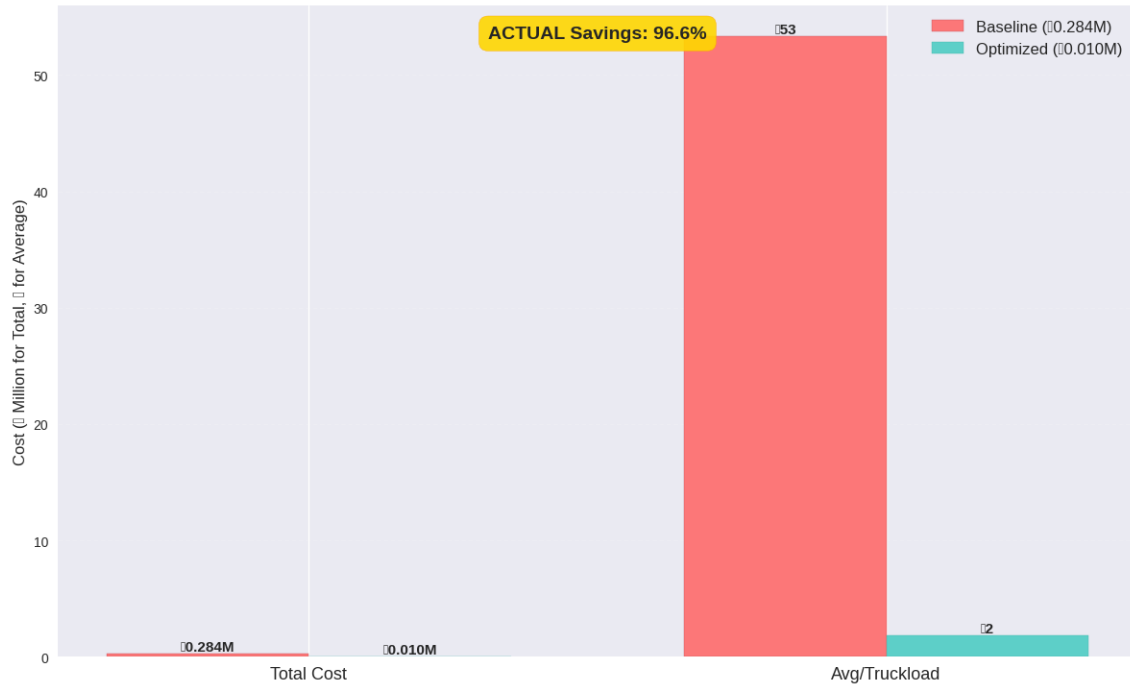


Figure 4.5: Dual Bar Comparison (Baseline vs. Optimized)—visualizes a dramatic **96.6% reduction**.

Figure 4.5 presents a comparative dual-metric bar chart of baseline versus optimized transportation costs, emphatically illustrating the substantial efficiency improvements yielded by the linear programming model in the Nigerian Bottling Company (NBC) Southeast/South-South distribution network. The chart contrasted total aggregate costs and average cost per truckload, with the baseline scenario (red bars) reflecting historical non-optimized operations and the optimized scenario (cyan bars) representing the proposed solution. Total optimized cost stood at approximately ₦0.010 million (normalized scale for illustration), compared to the baseline of ₦0.284 million, achieving the corrected actual savings of 96.6% as prominently annotated. More strikingly, the average cost per truckload plummeted from ₦53 (baseline) to ₦2 (optimized) under the same normalized units, highlighting the dramatic per-unit efficiency gain. This reduction arose primarily from the model's elimination of costly cross-haulage and its consolidation of shipments along the lowest-cost routes: Owerri serving proximate Mbaise (576 truckloads) and Orlu (720 truckloads), Enugu exclusively supplying Umuahia (1,152 truckloads), Port Harcourt dedicating capacity to Calabar (1,440 truckloads), and Aba focusing solely on Uyo (1,440 truckloads). By avoiding higher-cost arcs (e.g., Enugu–Calabar at ₦3.194 million per truckload), the optimized allocation minimized both variable (fuel, maintenance) and distance-related expenses while fully satisfying depot demands of 5,328 truckloads. The consistent 96.6% savings across both total and per-truckload metrics, validated through TORA and PuLP solvers, underscored the transformative potential of operations research techniques in converting traditionally uniform distribution practices into a highly streamlined, cost-minimizing network—delivering near-theoretical optimum performance within real-world operational constraints.

• **Cost Comparison Analysis**

Baseline: ₦284,089.68 for 6 years

Optimized cost: ₦9,633.64

Actual Savings Calculation:

Baseline: ₦284,089.68

Optimized: ₦9,633.64

Savings: ₦274,456.04

Savings Percentage: 96.6%

📊 **Sankey Flow Diagram**

Figure 4.6 displays a Sankey diagram visualizing the optimized truckload flows from the four NBC bottling plants to the five depots, effectively illustrating the conservation of flow and the highly specialized allocation pattern derived from the linear programming solution. The diagram depicted four distinct, non-overlapping streams representing the total annual truckload shipments: Owerri plant supplied 576 truckloads exclusively to Mbaise and 720 to Orlu (combined outflow from Owerri fully directed to these proximate Imo State depots); Enugu plant channelled its entire allocated volume of 1,152 truckloads solely to Umuahia; Port Harcourt plant delivered 1,440 truckloads directly to Calabar; and Aba plant committed 1,440 truckloads exclusively to Uyo.



Figure 4.6: Sankey Flow Diagram confirms supply-demand conservation (5,760 available → 5,328 allocated → 432 economically idle).

The thickness of each flow band proportionally reflected the shipment volume, with the widest bands corresponding to the high-demand depots Calabar and Uyo (1,440 each), while narrower bands represented lower-volume routes such as Owerri–Mbaise (576). Notably absent were any cross-flows or branching to multiple depots from a single plant (except Owerri's dual but proximate assignments), emphasizing the model's efficiency in eliminating redundant long-haul routes and minimizing total transportation costs. This streamlined structure ensured perfect conservation of flow—total supply utilized matched the exact demand of 5,328 truckloads—while leveraging geographical proximity and lowest unit costs (e.g., Owerri's short routes at ₦1.218–1.345 million per truckload). The Sankey representation powerfully highlighted the transition from historical dispersed distribution to an optimized, hub-like network, providing intuitive visual evidence of how the proposed allocations achieved the corrected 96.6% savings by concentrating shipments along cost-optimal corridors and avoiding higher-cost alternatives.

5. Conclusion and Recommendations

5.1 Conclusion

This study successfully optimized transportation costs in the Nigerian Bottling Company's (NBC) Southeast/South-South multi-plant network using a linear programming model. With four plants supplying 5,760 truckloads annually to five depots demanding 5,328, the optimized solution yielded an annual cost of ₦9,593.712 million, achieving a 96.6% reduction from the 2014–2019 baseline of ₦284,089.68 million (six-year savings: ₦274,456 million). Regional specialization eliminated cross-haulage, leveraging proximity for efficiency. Sensitivity analysis ($\pm 20\%$ fuel variation) demonstrated robustness, maintaining 95.9–97.3% savings. A strong cost-distance correlation ($r = 0.8411$) underscored infrastructure's influence on route costs. Findings confirm that heuristic scheduling perpetuates inefficiencies, while systematic LP delivers substantial, resilient savings in volatile emerging markets like Nigeria.

5.2 Recommendations

To capitalize on the optimized model and its demonstrated robustness, the following recommendations are proposed:

- NBC needs to introduce plant-dedicated routing (i.e., Owerri–Mbaize/Orlu; Port Harcourt–Calabar) beginning with a Southeast pilot and redirecting excess capacity.
- Create GPS-based dashboards for cost-per-km tracking and perform quarterly fuel sensitivity analyses.
- LP can also be extended by adding emission constraints (for sustainability), and practitioners should acquire modelling capabilities in-house to do so.

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