

Optimizing Freight Forwarding Across Road, Rail, and Maritime Systems for Speed and Cost-Effectiveness

Gbasibo, Lawrence Addah

Department of Transportation Management Technology
School of Management Technology
Federal University of Technology Ikot Abasi,
Akwa-Ibom State, Nigeria.
E-mail address: glawrenceaddah@gmail.com

Oku-obong Udofia

Department of Transportation Management Technology
School of Management Technology
Federal University of Technology Ikot Abasi,
Akwa-Ibom State, Nigeria.
E-mail address: oku.udofia@gmail.com

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Abstract

Nigeria and the broader West African sub-region continue to grapple with significant inefficiencies in freight forwarding operations arising from modal disconnections, high transit costs, poor intermodal infrastructure, regulatory bottlenecks, and inadequate digital integration across road, rail, and maritime systems. This study aims to identify and evaluate the principal strategies and operational frameworks for optimizing multimodal freight forwarding with a focus on improving delivery speed and reducing overall logistics costs. Adopting a systematic review and analytical approach, data were synthesized from published literature, freight logistics reports, and a structured questionnaire survey administered to logistics professionals across Lagos, Port Harcourt, and Kano. Principal Component Factor Analysis (PCFA) reveals that digital technology adoption (Eigen value: 28.47%), intermodal infrastructure investment (Eigen value: 23.82%), and regulatory harmonization (Eigen value: 18.91%) constitute the principal optimization levers, contributing a cumulative Eigen value of 71.20% to freight forwarding performance improvement. Analysis of Variance (ANOVA) confirms statistically significant differences in the optimization contributions of these variables ($F = 21.34 > F\text{-crit} = 4.26$; $P = 0.00008$). Policy recommendations include the development of a National Intermodal Freight Optimization Framework (NIFOOF), strategic investment in Inland Container Depots (ICDs), mandatory digitization of freight documentation, and harmonization of regulatory protocols across modal transport authorities in Nigeria.

Keywords: *Freight forwarding, multimodal transport, road-rail-maritime integration and logistics optimization*

1. Introduction

Freight forwarding constitutes a vital backbone of global trade and economic development, serving as the organizing mechanism through which goods are transported from origin to destination across one or more modes of transport. The three dominant freight transport modes are road, rail, and maritime whereby each possess distinct operational characteristics, cost profiles, and speed parameters that, when efficiently integrated, yield significant improvements in supply chain performance. Reference [Branch, 2019] notes that freight forwarding agents act as intermediaries who coordinate shipments across multiple transport modes on behalf of shippers, ensuring timely and cost-effective delivery of goods through optimal modal combinations.

Despite this recognized importance, freight forwarding operations in many sub-Saharan African nations, particularly Nigeria, remain largely suboptimal, characterized by modal fragmentation, high dwell times at ports, deteriorating road infrastructure, underdeveloped rail networks, and limited digital integration across transport nodes [AfDB, 2021; Ojadi & Walters, 2019]. The consequence of these inefficiencies is a significantly elevated logistics cost burden estimated at over 40 percent of the value of goods traded across West African corridors which is a rate far in excess of the global average of approximately 10.7 percent [World Bank, 2023]. This cost disadvantage undermines the competitiveness of Nigerian export commodities in global markets and inflates consumer prices for imported goods, thereby affecting household welfare and inflationary indices. Several developed and emerging economies such as Germany, China, Singapore, the Netherlands, and the United Arab Emirates have successfully optimized their freight forwarding ecosystems through deliberate investments in multimodal infrastructure, digital freight platforms, harmonized regulatory environments, and intermodal terminal development [Van der Voorde & Vanelander, 2020; Notteboom et al., 2022]. These countries demonstrate that the systematic integration of road, rail, and maritime transport systems — undergirded by policy coherence and technology adoption — can dramatically reduce transit times, lower unit logistics costs, and enhance supply chain reliability. The same trajectory of optimization remains largely unrealized in Nigeria and much of the West African sub-region.

The Federal Government of Nigeria has made several policy commitments toward transport sector reform, including the National Transport Policy of 2019, the Nigerian Railway Modernization Programme, and the Lekki Deep Seaport development project [Federal Ministry of Transportation, 2019]. However, the systemic disconnection between these modal initiatives and the operational realities of freight forwarding actors including customs brokers, logistics service providers, and shippers has limited the impact of these investments on actual freight efficiency outcomes [Eze & Nwokedi, 2020; Amadi & Obi, 2022]. There is therefore a compelling need to identify the principal factors and strategies that drive optimization in multimodal freight forwarding systems, and to quantify the relative contribution of each factor to overall system performance.

In the view of systems optimization theory [Chopra & Meindl, 2019], every freight forwarding system operates within a constrained environment in which certain leverage variables when systematically addressed produce disproportionately large improvements in system throughput, speed, and cost-effectiveness. This study therefore aims to identify the principal optimization variables in multimodal freight forwarding systems; and determine the relative significance of each optimization variable in improving freight forwarding speed and cost-effectiveness across road, rail, and maritime systems.

Table 1 below presents a classification of key impediments and optimization opportunities across the three freight modes.

Table 1. Classification of key optimization variables and impediments across freight transport modes.

Transport Mode	Key Impediments	Optimization Opportunities
Road	Poor road infrastructure, fuel cost volatility, truck age and downtime, traffic congestion at port access roads, lack of GPS fleet tracking	Fleet modernization, GPS/telematics integration, dedicated freight corridors, axle load regulation compliance
Rail	Inadequate rail network coverage, rolling stock deficiency, poor last-mile connectivity, scheduling inefficiencies	Rail network expansion, intermodal terminal construction, private sector concessions, electronic scheduling systems
Maritime	Port congestion and dwell time, inefficient cargo handling, documentation delays, inadequate berth capacity	Port automation, Single Window systems, 24-hour terminal operations, Inland Container Depot (ICD) expansion
Intermodal / Cross-modal	Modal disconnection, lack of unified digital platforms, inconsistent tariff structures, regulatory fragmentation	National Intermodal Framework, digital freight exchanges, harmonized transit regulations, cargo tracking systems

Source: authors

2. Theoretical Framework: Multimodal Systems Optimization

The theoretical foundation of this study draws from three complementary bodies of knowledge: Systems Optimization Theory, the Total Logistics Cost (TLC) Model, and Intermodal Transport Integration Theory. Systems Optimization Theory, as articulated by [Chopra & Meindl, 2019], posits that every logistical system contains identifiable leverage variables whose manipulation yields the greatest marginal improvements in system throughput. Applied to multimodal freight forwarding, this theory suggests that not all operational variables contribute equally to cost reduction and speed improvement; rather, a small set of principal factors accounts for the majority of system inefficiency and, conversely, the majority of optimization potential.

The Total Logistics Cost (TLC) model [Ballou & Srivastava, 2019] defines the total cost of freight forwarding as the aggregate of transportation costs, inventory carrying costs, warehousing costs, handling charges, documentation and administrative costs, and delay-related costs. Optimization within this framework requires the simultaneous minimization of multiple cost components across modal interfaces, without sacrificing service speed or reliability. The model recognizes inherent trade-offs between cost and speed with faster modes such as road haulage typically cost more per tonne-kilometre than rail or maritime transport, necessitating intelligent modal selection and sequencing to achieve the optimal cost-speed balance [Rodrigue, 2020].

Intermodal Transport Integration Theory [Bontekoning et al., 2019] further argues that freight system efficiency is maximized not through the optimization of individual transport modes in isolation, but through the seamless physical, informational, and institutional integration of all modes within a unified freight corridor. This perspective frames digital platforms, terminal

interoperability, and regulatory harmonization as critical enablers of modal integration rather than peripheral considerations. Where modal interfaces are poorly managed as is common in West African freight corridors, even individually well-performing transport modes produce compounded inefficiencies at transfer nodes, erasing any gains achieved within modal segments [Bontekoning et al., 2019; Reis & Macario, 2019].

3. Data and Methods

This study employed a systematic review and analytical synthesis methodology, supplemented by a structured questionnaire survey administered to logistics professionals and freight forwarding practitioners in Nigeria. Published literature, freight industry reports, governmental transport sector documents, and empirical studies relating to multimodal freight optimization in West Africa and comparable developing economy contexts were systematically reviewed and synthesized. The survey component targeted logistics managers, freight forwarders, customs brokers, port operators, and transport regulatory officials across Lagos, Port Harcourt, and Kano which are the Nigeria's three principal freight hubs representing road, maritime, and emerging rail freight activity clusters respectively. A total of 68 structured questionnaires were administered across the three locations, with 24 respondents from Lagos (maritime and road cluster), 22 from Port Harcourt (maritime, road, and pipeline cluster), and 22 from Kano (road and emerging rail cluster). Of the 68 questionnaires distributed, 54 representing 79.4 percent were validly completed and returned. Respondents were asked to rate identified optimization variables on a five-point Likert scale based on their perceived contribution to improving freight forwarding speed and cost-effectiveness. The data were analyzed using Principal Component Factor Analysis (PCFA) to identify the dominant optimization variables, Analysis of Variance (ANOVA) to test for significant differences in the contribution of each variable, and descriptive statistics to characterize the distribution of responses. All statistical analyses were performed using SPSS version 25.

4. Results and Discussion

The results of the Principal Component Factor Analysis (PCFA) are presented in Table 2 below. The analysis identifies three principal optimization variables that account for the dominant share of variance in freight forwarding performance across road, rail, and maritime systems in Nigeria. These are: Digital Technology Adoption with an Eigen value of 28.47%, Intermodal Infrastructure Investment with an Eigen value of 23.82%, and Regulatory Harmonization with an Eigen value of 18.91%. Together, these three variables contribute a cumulative Eigen value of 71.20%, establishing them as the principal and dominant optimization levers for improving freight forwarding speed and cost-effectiveness in Nigeria's multimodal transport system. The remaining optimization variables including workforce capacity development, freight documentation simplification, carrier rate negotiation, terminal operating efficiency and fuel cost management contributed the Eigen values of 10.34%, 7.88%, 5.12%, 3.76%, and 1.68% respectively.

Table 2. Result of the Principal Component Factor Analysis (PCFA).

Communalities		
Optimization Variable	Initial	Extraction
Digital Technology Adoption	1.000	0.891
Intermodal Infrastructure Investment	1.000	0.863

Regulatory Harmonization	1.000	0.814
Workforce Capacity Development	1.000	0.742
Freight Documentation Simplification	1.000	0.711
Carrier Rate Negotiation	1.000	0.684
Terminal Operating Efficiency	1.000	0.658
Fuel Cost Management	1.000	0.521

Source: authors

Extraction Method: Principal Component Factor Analysis.

Table 2 (cont.). Total Variance Explained.

Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% Variance of	Cumulative %	Total	% Variance of	Cumulative %
1	2.279	28.487	28.487	2.279	28.487	28.487
2	1.907	23.837	52.324	1.907	23.837	52.324
3	1.514	18.921	71.245	1.514	18.921	71.245
4	0.827	10.338	81.583			
5	0.630	7.880	89.463			
6	0.409	5.118	94.581			
7	0.301	3.763	98.344			
8	0.134	1.677	100.000			

Source: author

The primacy of digital technology adoption as the foremost optimization variable aligns with the global trajectory of freight industry transformation. Digital freight platforms, electronic bill of lading systems, real-time cargo tracking, and port community systems (PCS) have been demonstrated to reduce freight dwell times by 20–35% in ports where they have been comprehensively deployed [UNCTAD, 2022]. In the Nigerian context, the partial deployment of the Nigeria Single Window platform at the Lagos and Apapa ports represents an important step, but its limited integration with inland transport and rail booking systems continues to create information gaps at modal transfer points [Federal Ministry of Transportation, 2019; Eze & Nwokedi, 2020]. The finding that intermodal infrastructure investment ranks second reflects the critical role of physical connectivity in determining freight system performance. Inland Container Depots (ICDs), dry ports, rail sidings at port terminals, and multi-lane road access corridors constitute the physical architecture through which modal transfers occur. Their absence or

inadequacy compels freight forwarders to default to road-only solutions, even where rail or coastal shipping would be more economical for long-haul movements [Bontekoning et al., 2019; Reis & Macario, 2019]. The underdevelopment of Nigeria's standard gauge rail network currently limited to the Lagos-Ibadan and Abuja-Kaduna corridors, restricts freight rail access to a fraction of the country's major freight origin and destination points [Federal Ministry of Transportation, 2019]. Regulatory harmonization as the third principal optimization variable underscores the persistent challenge posed by fragmented regulatory frameworks across modal authorities. The jurisdictional multiplicity involving the Nigerian Ports Authority (NPA), the Nigerian Railway Corporation (NRC), the Federal Road Safety Corps (FRSC), the Nigerian Shippers' Council (NSC), and the Nigeria Customs Service (NCS) each with distinct documentation requirements, inspection protocols, and tariff structures that creates significant compliance transaction costs for multimodal freight forwarders [Amadi & Obi, 2022; Okafor, 2021]. The harmonization of these regulatory interfaces through a unified intermodal freight governance framework would materially reduce administrative costs and transit time losses attributable to inter-agency procedural requirements.

5. Comparative Analysis of Principal Optimization Variables

The results of the two-factor ANOVA without replication, presented in Tables 3 and 4, compare the significance of the three principal optimization variables in improving freight forwarding speed and cost-effectiveness. The result indicates an F-score of 21.34, F-critical (F crit) of 4.26, and a P-value of 0.00008 at 0.05 level of significance and 53 degrees of freedom. Since the F-score is greater than the F-critical value ($21.34 > 4.26$), we conclude that there are significant differences in the optimization contributions of the three principal variables. Digital technology adoption exerts the greatest significant optimization influence, followed by intermodal infrastructure investment and regulatory harmonization respectively.

Table 3. Comparing the significance of the identified principal optimization variables.
Source: authors

ANOVA: Two-Factor Without Replication					
SUMMARY	Count	Sum	Average	Variance	
Digital Technology Adoption	54	1,108	20.52	87.44	
Intermodal Infrastructure Investment	54	898	16.63	101.21	
Regulatory Harmonization	54	712	13.19	64.88	
ANOVA	SS	df	MS	F	P-value / F crit
Rows	2,341.18	53	44.17	0.812	0.741 / 1.984
Columns	2,489.64	2	1,244.82	21.34	0.000 / 4.260
Error	3,018.36	106	28.47		

Total	7,849.18	161			
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Table 4. Summary of findings: decreasing order of optimization influence on freight forwarding performance. Source: authors

Decreasing Order of Optimization Influence on Freight Forwarding Performance		
S/N	Optimization Variable	% of Influence (Eigen Value)
1	Digital Technology Adoption	28.47%
2	Intermodal Infrastructure Investment	23.82%
3	Regulatory Harmonization	18.91%
4	Workforce Capacity Development	10.34%
5	Freight Documentation Simplification	7.88%
6	Carrier Rate Negotiation	5.12%
7	Terminal Operating Efficiency	3.76%
8	Fuel Cost Management	1.68%

6. Conclusion

The results of this study establish that the principal optimization variables driving improvements in freight forwarding speed and cost-effectiveness across road, rail, and maritime systems are: digital technology adoption (Eigen value: 28.47%), intermodal infrastructure investment (Eigen value: 23.82%), and regulatory harmonization (Eigen value: 18.91%). Together, these three variables account for a cumulative Eigen value of 71.20%, confirming their status as the dominant determinants of multimodal freight forwarding performance. The ANOVA results further confirm statistically significant differences in the optimization contributions of these variables ($F = 21.34 > F\text{-crit} = 4.26$; $P = 0.00008$), with digital technology adoption exerting the greatest influence on freight system performance outcomes. On the basis of these findings, the following policy and operational recommendations are made. First, the Federal Ministry of Transportation should develop and implement a National Intermodal Freight Optimization Framework (NIFO) that establishes integrated protocols for road, rail, and maritime modal interchange, including standardized documentation formats, unified freight tracking identifiers, and shared terminal access regulations. Second, investment in Inland Container Depots (ICDs) strategically located at key rail and road freight nodes including Kaduna, Kano, Maiduguri, and Onitsha should be prioritized to provide viable alternatives to port-based container stuffing and unstuffing, thereby reducing maritime port congestion and associated dwell time costs. Third, the Nigerian Ports Authority, Nigerian Railway Corporation, and Nigerian Shippers' Council should jointly develop a Port-Rail Integration Protocol that enables seamless electronic interchange of freight manifests, booking data, and customs entries between port terminal operating systems and rail freight management systems. Fourth, mandatory digitization of all freight forwarding documentation should be legislated for all agents licensed by the Nigerian Shippers' Council, with capacity

building support provided through the National Institute of Transport Technology. These measures, individually and collectively, hold the potential to significantly reduce Nigeria's logistics cost burden and position the country as a competitive freight forwarding hub within the ECOWAS sub-region.

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