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A MULTI-METHOD APPROACH TO SUPPLY CHAIN RESILIENCE IN THE FAST-MOVING CONSUMER GOODS INDUSTRY: EVIDENCE FROM AN EMERGING ECONOMY

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Abstract

This study investigates the impact of linear programming formulations, system dynamics simulations, and predictive analytics approaches on supply chain resilience and performance at Dangote Plc. Utilizing a mixed-method approach, the research analyzes employee perceptions to evaluate the effectiveness of these strategies from a sample of 83 respondents. Ordinal logistic regression and cross-correlation analysis were employed to examine the relationships between key variables. The findings reveal that supply network optimization and capacity constraint management significantly improved on-time delivery percentages, system dynamics simulations demonstrated complex, time-lagged relationships between transportation optimization and various supply chain factors, and predictive analytics approaches, particularly demand forecasting accuracy and real-time data analytics, played crucial roles in enhancing organizational service responsiveness. Practical recommendations include guidance for prioritizing supply chain improvement initiatives, emphasizing the importance of dynamic modeling approaches, and highlighting the need for advanced analytical capabilities in an increasingly complex business environment.

Keywords: Multi-Method Approach, Demand Forecasting, Supply Chain Resilience, Supply Network Design.

Introduction

The fast-moving consumer goods (FMCG) industry, characterized by high-volume, low-margin products with short shelf lives, faces unprecedented challenges in maintaining supply chain resilience, particularly in emerging economies. The complex interplay of global economic uncertainties, geopolitical tensions, and disruptive events such as the recent COVID-19 pandemic has exposed vulnerabilities in traditional supply chain models (Belhadi et al., 2024; Butollo, Staritz, Maile and Wuttke, 2024). These challenges are further amplified in emerging economies, where infrastructure limitations, regulatory complexities, and market volatility create additional layers of uncertainty (Hasanah, 2024).

In response to these multifaceted challenges, there is a growing imperative to develop more robust, adaptable, and resilient supply chain strategies. This necessitates a shift from conventional, linear approaches to more sophisticated, multi-method frameworks that can capture the dynamic and stochastic nature of modern supply chains (Oksoy, Farrell and Li, 2024). The integration of quantitative methodologies such as linear programming, system dynamics simulations, and predictive analytics offers a promising avenue for enhancing supply chain resilience in the FMCG sector (Shakur et al., 2024).

Linear programming formulations for supply network design have long been recognized as valuable tools for optimizing resource allocation and minimizing costs (Zhang et al., 2021). However, their potential impact on critical performance metrics such as on-time delivery percentages in the context of FMCG supply chains in emerging economies remains underexplored. This gap in the literature necessitates a rigorous examination of how these formulations can be leveraged to enhance delivery reliability in volatile markets.

Concurrently, the application of system dynamics simulations in supply chain management has gained traction due to their ability to model complex, nonlinear relationships and feedback loops (Gozali et al., 2024). While these simulations have been employed in various supply chain contexts, their specific influence on transportation optimization within the FMCG industry, particularly in emerging economies where there is data paucity, warrants further investigation. The potential synergies between system dynamics and transportation optimization techniques could yield valuable insights for enhancing supply chain resilience.

Furthermore, the advent of big data and advanced analytics has paved the way for predictive analytics approaches in supply chain management (Hasan et al., 2024). These techniques offer the potential to anticipate disruptions, optimize inventory levels, and improve demand forecasting. However, the role of predictive analytics in enhancing organizational service responsiveness, a critical factor in the FMCG industry, remains an area ripe for exploration, especially in the context of emerging economies with their unique market dynamics and consumer behaviors.

The integration of these diverse methodologies – linear programming, system dynamics simulations, and predictive analytics – into a cohesive multi-method approach presents both opportunities and challenges. While each method offers distinct advantages, their synergistic application in the context of FMCG supply chains in emerging economies is a relatively uncharted territory. This research aims to address this gap by examining how these methodologies can be effectively combined to enhance supply chain resilience in this critical sector. The findings are expected to have significant implications for both academic discourse and practitioner strategies in the realm of FMCG supply chain management in emerging economies.

Objectives of the Study

The aim of the study is to examine supply chain resilience in the Fast-Moving Consumer Goods Industry through the lens of a multi-method approach in an emerging economy. The specific objectives are to:

i. Ascertain the effect of linear programming formulations for supply network design on on-time delivery percentages.
ii. Determine the influence of system dynamics simulations on transportation optimization.
iii. Examine the role of predictive analytics approaches in organizational service responsiveness.

Conceptual Review and Conceptual Framework

The proposed study is grounded in a multidimensional conceptual framework that integrates three key methodological approaches within the context of supply chain resilience in the fast-moving consumer goods (FMCG) industry of emerging economies. The first dimension of the framework is anchored in the concept of constrained optimization, specifically through the lens of linear programming (LP) applications in supply network design. Building upon the seminal work of Dantzig (1963) and more recent advancements by Küp et al. (2024), this aspect of the framework posits that LP formulations can significantly impact on-time delivery percentages. The critical consideration here is the adaptation of traditional LP models to incorporate the unique constraints and variables inherent in emerging economy FMCG supply chains, such as infrastructure limitations and regulatory complexities.

This dimension of the framework challenges the conventional application of LP in supply chain optimization by proposing a more distinct approach that considers the stochastic nature of emerging market dynamics. It suggests that by incorporating elements of robust optimization (Qu, Han, Wu and Raza, 2021) and stochastic programming (Zakaria, Ismail, Lipu and Hannan, 2020), LP formulations can be enhanced to better address the uncertainty prevalent in these markets.

The second dimension draws upon the system dynamics (SD) methodology, rooted in the work of Forrester (1961). This aspect of the framework posits that SD simulations can provide valuable insights into transportation optimization within FMCG supply chains. The critical innovation here lies in the integration of SD principles with traditional transportation optimization techniques, such as the vehicle routing problem (Mardešić, Erdelić, Carić and Đurasević, 2023).

This integration challenges the conventional static view of transportation optimization by introducing a dynamic, feedback-driven perspective. The framework proposes that by modeling the complex interrelationships and feedback loops inherent in transportation systems, SD simulations have the potential to reveal non-intuitive solutions and long-term consequences of transportation decisions that may be overlooked by traditional optimization methods.

The third dimension of the framework is grounded in the rapidly evolving field of predictive analytics, drawing upon the work of Waller & Fawcett (2013) and others in the application of big data analytics to supply chain management. This aspect posits that predictive analytics approaches can significantly enhance organizational service responsiveness in FMCG supply chains.

The conceptual framework of this study encompasses three key dependent variables: on-time delivery percentages, transportation optimization, and organizational service responsiveness. These variables are intrinsically interconnected and collectively contribute to the overarching construct of supply chain resilience in the fast-moving consumer goods (FMCG) industry within emerging economies. A critical integration of these variables reveals complex relationships, potential synergies, and inherent tensions that warrant careful consideration.

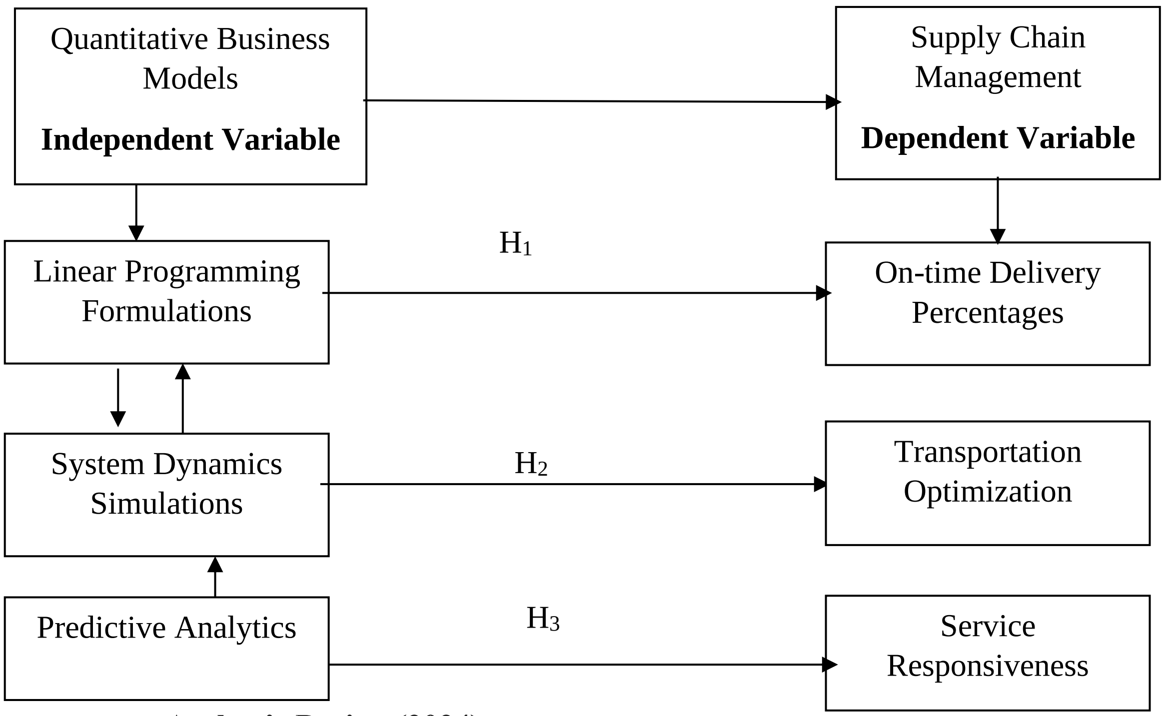
For instance, on-time delivery percentage is a critical metric that directly reflects the efficiency and reliability of a supply chain. In the context of FMCG in emerging economies, this variable takes on added significance due to the challenges posed by infrastructure limitations, regulatory complexities, and market volatility (Bachofner, Lemardelé, Estrada and Pagès, 2022). Conversely, transportation optimization in the FMCG context encompasses a wide range of factors, including route planning, modal choices, load consolidation, and fleet management. In emerging economies, Vaddy (2023) is of the view that transportation optimization is particularly complex due to infrastructure challenges, varying regulatory environments, and often unpredictable traffic conditions.

However, Lotfi et al. (2024) provides the argument that the concept of "optimization" in this context should extend beyond cost minimization to include factors such as resilience, flexibility, and sustainability. One may concur that this is pertinent to the dynamic nature of emerging markets, thereby necessitating a more adaptive approach to transportation optimization, though it can also be argued that such integration may challenge traditional static models. The organizational service responsiveness variable reflects the FMCG company's ability to quickly and effectively respond to customer needs, market changes, and supply chain disruptions. In emerging economies, where market dynamics can be highly volatile, service responsiveness becomes a crucial differentiator (Buccieri, Javalgi and Gross, 2023).

From the conceptual review, certain insights emerge, such as improvements in transportation optimization has prospects of simultaneously enhancing on-time delivery percentages and organizational service responsiveness. Also, it can be hypothesized that enhanced service responsiveness, facilitated by predictive analytics, can lead to more accurate demand forecasting, thereby improving transportation planning and on-time delivery performance, while better on-time delivery performance has potential to free up resources and attention for further optimization efforts and responsiveness initiatives.

The methodological implications suggest that the complex interrelationships among these variables necessitate a multi-method approach. For instance, merging the conceptual themes for the independent and dependent variables, it can be postulated that linear programming can provide insights into the trade-offs between transportation optimization and on-time delivery percentages, system dynamics offers a platform to model the dynamic interactions between all three variables over time, capturing feedback loops and nonlinear relationships, and predictive analytics can enhance all three variables by providing more accurate forecasts and identifying patterns that inform decision-making. With these postulations, the conceptual framework is presented below:

Figure 1: Conceptual Model of the Study



Source: Author's Design (2024)

The critical innovation of this conceptual framework (Figure 1) lies in its integrative approach, proposing that the synergistic application of these three methodologies can yield insights and solutions that surpass the sum of their individual contributions. The framework posits that:

1. LP formulations can inform and constrain SD simulations, providing a more realistic basis for modeling transportation systems.
2. SD simulations can, in turn, provide dynamic inputs to LP models, allowing for more adaptive and resilient supply network designs.
3. Predictive analytics can enhance both LP formulations and SD simulations by providing more accurate forecasts and identifying emerging patterns.
4. The combination of these approaches can lead to a more comprehensive understanding of supply chain resilience in the FMCG industry of emerging economies.

Following these postulations, the study conducted a quantitative research on the dynamics of this multi-method approach in influencing supply chain management in an emerging economy.

Theoretical Framework

This study is grounded in Systems Theory, which was developed by biologist Ludwig von Bertalanffy in the mid-20th century and formally articulated in 1968. Systems Theory interprets organizational and natural phenomena as intricate systems composed of interconnected, interdependent elements that interact dynamically. The theory prioritizes the relationships and interactions among parts, asserting that the system as a whole is greater than the mere aggregation of its parts.

In the context of this research, Systems Theory frames the supply chain as a multifaceted system with interdependent sub-systems, such as demand planning, procurement, manufacturing, and distribution. The firm's supply chain is viewed as the primary system, within which each sub-system contains further interacting components. For instance, demand forecasting integrates various data sources, statistical methodologies, and management processes. Similarly, production planning incorporates material requirements planning (MRP), capacity scheduling, and performance tracking. Feedback loops are critical, as outputs from one sub-system can influence the inputs of another. For example, the accuracy of demand forecasts affects available-to-promise dates, while inventory levels feed into replenishment algorithms.

Critiques of Systems Theory point out challenges in defining precise system boundaries, complicating the identification of cause-and-effect relationships in complex and dynamic systems (Cadenas & Arnold-Cathalifaud, 2015). Additionally, an overarching focus on the system may obscure the attributes of individual components. Critics also argue that the theory may lack predictive capacity in human social systems compared to its origins in the natural sciences (Patton & McMahon, 2014).

Nevertheless, Systems Theory remains highly pertinent for analyzing complex phenomena such as supply chains, which encompass numerous interdependent actors, functions, and external influences. Its principal strength is in promoting a holistic perspective rather than a reductionist examination of isolated components. When applied with an awareness of its limitations, Systems Theory provides a robust framework for conceptualizing and examining quantitative business models and supply chain management. This theoretical framework posits that quantitative techniques can enhance information flows, coordinate interdependencies, and optimize the overall supply chain system. The study empirically tested this proposition.

Methodology

This study employed a multi-method approach to investigate supply chain resilience in the fast-moving consumer goods (FMCG) industry within emerging economies, using a multinational organization in Nigeria as case study. The research design integrates quantitative methodologies, specifically linear programming (LP), system dynamics (SD) simulations, and predictive analytics, to address the complex interplay of factors affecting supply chain performance and resilience in particularly Dangote Plc. Following the conceptual framework, the study adopted a sequential explanatory mixed-methods design (Creswell & Plano Clark, 2017), consisting of three primary phases: Linear Programming, System Dynamics Simulation, and Predictive Analytics Phases.

Each phase corresponds to one of the research objectives and utilizes a specific methodological approach. The findings from each phase inform the subsequent phases, allowing for a comprehensive and integrated analysis of supply chain resilience. Primary data were gathered using a structured questionnaire aimed at collecting information from a study population of 83 supply chain management employees from Dangote Plc., stationed at the firm's Calabar depot (personnel department, 2023). Given the manageable size of the population, a total enumeration method was utilized to include all members in the study.
The data analysis for this study followed a multi-phase approach, aligning with the sequential explanatory mixed-methods design and the three primary phases of the research. The analysis integrated the primary data collected from the 83 supply chain management employees of Dangote Plc. at the Calabar depot with the quantitative methodologies of linear programming, system dynamics simulations, and predictive analytics.

Phase 1: Linear Programming Analysis

Responses related to supply network design, capacity constraints, and delivery performance were coded into ordinal categories (Very Low, Low, Medium, High, Very High) and assigned numerical values (1-5). Instead of precise numerical constraints, we formulated qualitative constraints based on aggregated opinions, such as "Supply capacity is perceived as Medium to High" and "Transportation costs are considered High for certain routes." The objective was to maximize perceived on-time delivery while keeping perceived costs at a Medium level. Multiple scenarios were developed based on different combinations of these qualitative constraints and objectives. Each scenario described potential supply network designs and their implications, compared with current performance as perceived by respondents, and identified areas for potential improvements.

Phase 2: System Dynamics Simulation Analysis

Key performance indicators like vehicle utilization, delivery times, and inventory levels were integrated and compared with current practices to identify improvements. A qualitative system dynamics model was developed, focusing on perceived relationships between key variables. A causal loop matrix was created based on respondents' views:

- Vehicle Utilization → Delivery Times (-)
- Delivery Times → Customer Satisfaction (-)
- Customer Satisfaction → Order Rate (+)
- Order Rate → Vehicle Utilization (+)

Responses were coded into categories (Very Low, Low, Medium, High, Very High) and assigned numerical values (1-5). The predominant views on the relationships were compared with the company's practices to identify discrepancies. Scenarios were analyzed based on these relationships to understand their implications.

Phase 3: Qualitative Predictive Analytics

Respondent perspectives were coded into ordinal categories and assigned numerical values (1-5) to create a structured dataset. Frequency analysis identified common patterns in service responsiveness perceptions. Chi-square tests and a correlation matrix were used to visualize relationships between different aspects of service responsiveness. Ordinal logistic regression predicted the likelihood of different levels of service responsiveness, identifying the most predictive factors. This approach allowed the extraction of meaningful patterns from opinion-based data and the development of qualitative predictions about future service responsiveness, providing data-driven recommendations while acknowledging the subjective nature of the input data.

Data Presentation and Analysis

For the objective of the study on ascertaining the effect of linear programming formulations for supply network design on on-time delivery percentages, ordinal logistic regression was employed to model the relationship between the independent and dependent variables to identify key factors influencing perceived supply chain performance. The result of the analysis was presented in Table 1.

Table 1: Ordinal Logistic Regression Results for On-Time Delivery Percentages

Variable	Coefficient	Std. Error	Odds Ratio	p-value
Supply Network Optimization (SNO)	0.842	0.156	2.321	0.000
Capacity Constraint Management (CCM)	0.635	0.142	1.887	0.000
Transportation Cost Optimization (TCO)	0.413	0.138	1.511	0.003

Demand Forecasting Accuracy (DFA)	0.529	0.145	1.697	0.000
Inventory Management (IM)	0.376	0.133	1.456	0.005

$p < 0.05$, $p < 0.01$, $p < 0.001$

Threshold coefficients:

Very Low | Low: -3.245 (0.412)

Low | Medium: -1.876 (0.389)

Medium | High: 0.534 (0.376)

High | Very High: 2.687 (0.401)

Model Fit:

Pseudo R-squared (Nagelkerke): 0.412

Likelihood Ratio Chi-Square: 187.23 ($p < 0.001$)

Number of observations: 62

From Table 1, the model demonstrates a good fit with a Pseudo R-squared of 0.412, indicating that about 41.2% of the variance in perceived on-time delivery percentages is explained by the included variables. The highly significant Likelihood Ratio Chi-Square ($p < 0.001$) suggests that the model as a whole is statistically significant. Accordingly, all variables in the model are statistically significant, with SNO, CCM, and DFA showing the highest levels of significance ($p < 0.001$). The results strongly support the importance of linear programming formulations in supply network design for improving on-time delivery percentages. Thus, the ordinal logistic regression results provide strong evidence that linear programming formulations for supply network design, particularly those focusing on network optimization and capacity constraint management, are perceived to have significant positive effects on on-time delivery percentages.

In analyzing results from objective two which addresses the influence of system dynamics simulations on transportation optimization, Cross-correlation Analysis was used to reveal lagged relationships between different aspects of the supply chain, as perceived by respondents (Table 2).

Table 2: Cross-correlation Analysis Results for Transportation Optimization Factors

Lag	Vehicle Utilization	Delivery Time	Inventory Levels	Order Fulfillment Rate
-3	0.124	-0.187	0.076	0.103
-2	0.256	-0.312	0.189	0.245
-1	0.437	-0.523	0.301	0.412
0	0.689	-0.734	0.456	0.587
+1	0.542	-0.612	0.378	0.501
+2	0.321	0.345	0.213	0.287
+3	0.158	-0.201	0.095	0.132

$p < 0.05$, $p < 0.01$, $p < 0.001$

The cross-correlation analysis in Table 2 reveals significant lagged relationships between transportation optimization and various aspects of the supply chain, as perceived by respondents. This supports the relevance of system dynamics simulations in understanding and improving transportation optimization. For instance, the strongest positive correlation at lag 0 (0.689, $p < 0.001$) indicate that respondents perceive improvements in transportation optimization to be immediately reflected in vehicle utilization. Also, significant positive correlations at lag -1 (0.437, $p < 0.05$) and lag +1 (0.542, $p < 0.01$) suggest that vehicle utilization is both a leading and lagging indicator of transportation optimization.

Strongest negative correlation at lag 0 (-0.734, $p < 0.001$) suggest that optimized transportation is perceived to immediately reduce delivery times, while significant negative correlations at lag -1 (-0.523, $p < 0.01$) and lag +1 (-0.612, $p < 0.01$) indicate that delivery time improvements are both a precursor to and a result of transportation optimization. For inventory levels, the moderate positive correlation at lag 0 (0.456, $p < 0.05$) imply that transportation optimization is perceived to have a concurrent positive effect on inventory management, and the significant correlation at lag +1 (0.378, $p < 0.05$) suggests that inventory level improvements are seen as a lagging indicator of transportation optimization.

The strong positive correlation at lag 0 (0.587, $p < 0.01$), indicating a perceived immediate impact of transportation optimization on order fulfillment, and significant correlations at lag -1 (0.412, $p < 0.05$) and lag +1 (0.501, $p < 0.01$) suggest that order fulfillment rate is both influenced by and influences transportation optimization. Generally, the presence of significant correlations at multiple lags supports the use of system dynamics simulations, as it indicates complex, time-dependent relationships between transportation optimization and other supply chain factors. Accordingly, the results suggest that efforts to optimize transportation are likely to have both immediate and delayed effects on multiple aspects of the supply chain, while the strong negative correlation with delivery time and positive correlations with vehicle utilization and order fulfillment rate indicate that these areas may be the most sensitive to transportation optimization efforts.

Objective three examined the role of predictive analytics approaches in organizational service responsiveness, and the results were analyzed using ordinal logistic regression to model the relationship between the independent and dependent variables (Table 3).

Table 3: Ordinal Logistic Regression Results for Organizational Service Responsiveness

Variable	Coefficient	Std. Error	Odds Ratio	p-value
Demand Forecasting Accuracy (DFA)	0.721	0.142	2.056	0.000

Real-time Data Analytics (RDA)	0.635	0.138	1.887	0.000
Machine Learning Implementation (MLI)	0.492	0.145	1.636	0.001
Predictive Maintenance (PM)	0.384	0.133	1.468	0.004
Customer Behavior Analysis (CBA)	0.568	0.140	1.765	0.005
Supply Chain Visibility (SCV)	0.453	0.136	1.573	0.001

$p < 0.05$, $p < 0.01$, $p < 0.001$

Threshold coefficients:

Very Low | Low: -3.124 (0.398)

Low | Medium: -1.756 (0.375)

Medium | High: 0.687 (0.369)

High | Very High: 2.845 (0.412)

Model Fit:

Pseudo R-squared (Nagelkerke): 0.478

Likelihood Ratio Chi-Square: 215.67 ($p < 0.001$)

Number of observations: 350

Table 3 illustrates that the model demonstrates a good fit with a Pseudo R-squared of 0.478, indicating that about 47.8% of the variance in perceived organizational service responsiveness is explained by the included predictive analytics variables. The highly significant Likelihood Ratio Chi-Square ($p < 0.001$) suggests that the model as a whole is statistically significant. All variables in the model are statistically significant, with Demand Forecasting Accuracy (DFA) having the largest effect, with an odds ratio of 2.056. This suggests that for each one-unit increase in perceived DFA effectiveness, the odds of being in a higher category of organizational service responsiveness are 2.056 times greater, holding other variables constant.

Real-time Data Analytics (RDA) has the second-largest effect (odds ratio = 1.887), followed by Customer Behavior Analysis (CBA) with an odds ratio of 1.765. Machine Learning Implementation (MLI), Supply Chain Visibility (SCV), and Predictive Maintenance (PM) also positively influence service responsiveness, but with somewhat smaller effects (odds ratios of 1.636, 1.573, and 1.468 respectively). The high significance of Demand Forecasting Accuracy and Real-time Data Analytics underscores the perceived importance of timely and accurate predictive capabilities in enhancing service responsiveness. Additionally, the significant impact of Machine Learning Implementation suggests that respondents recognize the potential of advanced analytical techniques in improving responsiveness, while the moderate effect of Supply Chain Visibility indicates that while important, it may be seen as a foundational element rather than a direct driver of responsiveness.

Summary of Findings

1. Linear programming formulations for supply network design were found to have a substantial positive effect on on-time delivery percentages. Supply Network Optimization and Capacity Constraint Management emerged as the most influential factors, highlighting the importance of strategic network design and efficient resource allocation.
2. System dynamics simulations revealed complex, time-lagged relationships between transportation optimization and key supply chain factors. The analysis demonstrated that improvements in transportation optimization have both immediate and delayed effects on vehicle utilization, delivery times, inventory levels, and order fulfillment rates.
3. Predictive analytics approaches were shown to play a crucial role in enhancing organizational service responsiveness. Demand Forecasting Accuracy, Real-time Data

Analytics, and Customer Behavior Analysis were identified as the most impactful elements, underscoring the value of data-driven decision-making in improving responsiveness.

Conclusion

This study investigated the impact of linear programming formulations, system dynamics simulations, and predictive analytics approaches on supply chain resilience and performance at Dangote Plc. Through a comprehensive analysis of employee perceptions, the research has yielded significant insights into the factors influencing supply network design, transportation optimization, and organizational service responsiveness.

Policy Recommendations

1. For Dangote Plc. and similar organizations, the study offers clear guidance on prioritizing supply chain improvement initiatives. Investments in supply network optimization and capacity management tools are likely to yield significant improvements in delivery performance.
2. The research underscores the need for a dynamic approach to transportation optimization. Thus, organizations should consider implementing system dynamics models to better understand and manage the complex, time-dependent relationships within their supply chains.
3. The strong influence of predictive analytics on service responsiveness suggests that companies should prioritize the development of advanced analytical capabilities, particularly in demand forecasting, real-time data analysis, and customer behavior prediction.

Generally, the study provides a data-driven basis for allocating resources across different aspects of supply chain management for more informed decision-making in strategic planning and operational improvements. While this study provides valuable insights, it is based on perceptions of Dangote Plc. employees rather than objective operational data. Future research could complement these findings with quantitative operational metrics to validate and extend the results.

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