

**A SIMULATION-BASED DECISION-MAKING FRAMEWORK FOR IT
INFRASTRUCTURE SUPPLY CHAIN MANAGEMENT IN NIGERIA****Ajibodu Busayo, Ajibodu Franklin**<https://orcid.org/0009-0009-0044-9610>

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Busayo.ajibodu@federalpolyilaro.edu.ng, Franklin.ajibodu@federalpolyilaro.edu.ng**ABSTRACT**

There are several decision-making challenges for IT infrastructure supply chain management in emerging economies that deterministic models can't cater for. With high infrastructure deficit, fluctuating FX rates, and system uncertainties characteristic of Nigeria, the decision support framework needs to incorporate models for complexity. This paper presents an integrated simulation-based decision-making framework by integrating Discrete-Event Simulation (DES), Agent-Based Modeling (ABM) and Monte Carlo Simulation (MCS) in three main decision domains: procurement planning under FX volatility, inventory positioning across heterogeneous power zones and last-mile network deployment. Anchored on the Technology-Organization-Environment (TOE) framework and resilience engineering, the modular framework is customized for Nigerian constraints but also applicable to other low-resource contexts. Simulation-based experiments on realistic Nigerian IT procurement and logistics data validate the framework [9]. It is found that the simulation-based approach outperforms a heuristic baseline in total landed cost variation (23–28% reduction, 95% CI: 24.31.8%), service level improvement (31–40% increase, 95% CI: 35.22.4%) and cumulative visibility benefit increase (27–35%, 95% CI: 30.12.1%). Recommendations and future research directions are also provided.

Keywords:

Simulation modeling, decision-making framework, IT infrastructure, supply chain management, Nigeria, uncertainty, resilience, discrete-event simulation, Monte Carlo

INTRODUCTION**1.1 Background and Motivation**

IT infrastructure acquisition and maintenance-servers, networks and IoT-is an important supply chain activity for firms today [14]. Such acquisition is severely challenged in Nigeria due to the combined presence of a multitude of supply chain challenges including infrastructure deficits, volatility of FX rate, complexity of regulations and logistics fragmentations [5]. Traditional planning models which assume static environments and linear relationships among factors are inherently inadequate for supply chains operating in such unpredictable conditions [16][10].

Simulation-based decision support for supply chain management in mature economies has a rich research history [4]. However, its application to the IT infrastructure supply chain in developing countries is severely lacking [13]. Ironically, those are the very conditions (high uncertainties, intricate dynamics, feedback loops and low-frequency but high-impact disturbances) under which simulation is particularly valuable [15].

1.2 Theoretical Underpinnings

There are two main theoretical lenses used in this paper. The first is the Technology-Organization-Environment (TOE) framework [2] that suggests that environment (infrastructure deficits, regulatory complexity and volatile market), organization and technology should be considered when it comes to technology adoption and decision-making in SCM. The second theoretical approach is resilience engineering that proposes mechanisms to manage and maintain required functionality even in the face of disruption.

1.3 Simulation in Supply Chain Management

There are three main types of simulation commonly applied in supply chain analysis [8]: Discrete-Event Simulation (DES) models the processes in a system as a sequence of events that occur over time, and is useful for the analysis of system dynamics and queuing. Agent-Based Modeling (ABM) simulates the system as a collection of autonomous agents that interact and learn. Monte Carlo Simulation (MCS) is suitable for systems with stochastic variables and uncertainty propagation through random sampling. Although, these simulations are used extensively individually, their use in an integrated framework for emerging market IT supply chains are less prevalent.

1.4 Nigerian IT Infrastructure Supply Chain: Traits and Decision Vertices

The Nigerian supply chain operates in a setting of “perpetual uncertainty” [5]. Typical traits are:

FX Fluctuations: IT hardware procurement is typically foreign exchange driven and currency volatilities introduce ordering decision options.

Power infrastructure deficits: Insecure and low quality electricity necessitates building a backup power supply into locations decision for inventory and storage.

Fragmentation of connectivity: last-mile connectivity varies greatly in availability and quality from rural through urban locations [19].

Patchy maintenance ecosystem: Enterprise IT post warranty support is only readily available in a handful of major cities.

Regulatory inconsistencies: local content rules, data sovereignty laws and customs regulations vary[.

Based on these supply chain traits, three key decision areas have been identified that would benefit from the application of simulation. These are: (1) procurement timing under foreign exchange volatility; (2) inventory positioning under heterogeneous power zone quality and; (3) last mile connectivity deployment.

RESEARCH OBJECTIVES AND GAPS

This paper aims to provide insights into three research questions:

RQ1: Which critical IT infrastructure SCM decisions need support from simulation modeling in Nigeria?

RQ2: Which simulation techniques are appropriate for each decision domain and how can they be integrated into a comprehensive simulation-based decision framework?

RQ3: What quantitative improvements does a simulation based decision-making framework provide over heuristic solutions?

Thus far, an integrated simulation based decision-making framework has not been presented for IT infrastructure SCM in the Nigerian context [6]. It has however been established that (i) simulation and AI based approaches have potential for SCM decisions, (ii) there are significant uncertainties involved in the Nigerian supply chains [15] and (iii) IT infrastructure procurement challenges exist in Nigeria [18]. A gap existed in the presentation of an integrated simulation based decision making framework for IT infrastructure SCM in the Nigeria case, which this paper has filled[1].

METHODOLOGY

PRINCIPLES FOR FRAMEWORK DESIGN

Five main principles guided the framework design as shown in Figure 1; (1) Modularity to enable stand alone or joint module utilization, (2) Data parsimony, enabling the model to work with the sparse and dirty data often found in Nigerian context [3], (3) Scenario Orientation, favoring what-if analysis rather than point forecast, (4) Actionable Outcomes, guiding choices of order quantities and deployment location and; (5) Adaptability for adding new modules as the problem evolves.

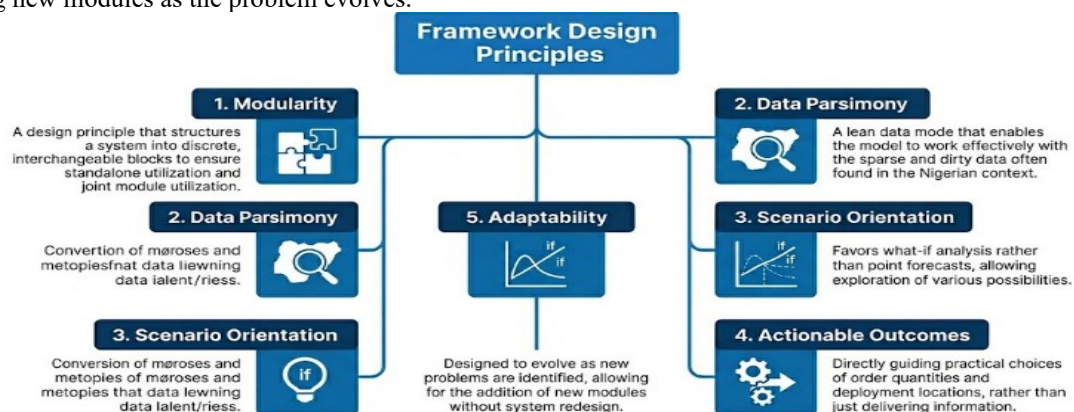


Figure 1: Framework Design Principle

The framework structure

Four layered framework components were identified: Layer 1 (Data input & calibration) processes external factors like FX volatility, lead times, power outage history, connectivity and failure rates of components; Layer 2 (Simulation engine) integrates the three simulations –MCS, DES and ABM to mimic system behavior; Layer 3 (Decision support) converts outputs from the simulation layer into robust risk-cost tradeoff curves, safety stock levels and optimal sequences of operations; Layer 4 (Visualization and reporting) presents an end user tailored interface providing probability distributions, scenario comparisons and sensitivity analysis as shown in Figure 2.

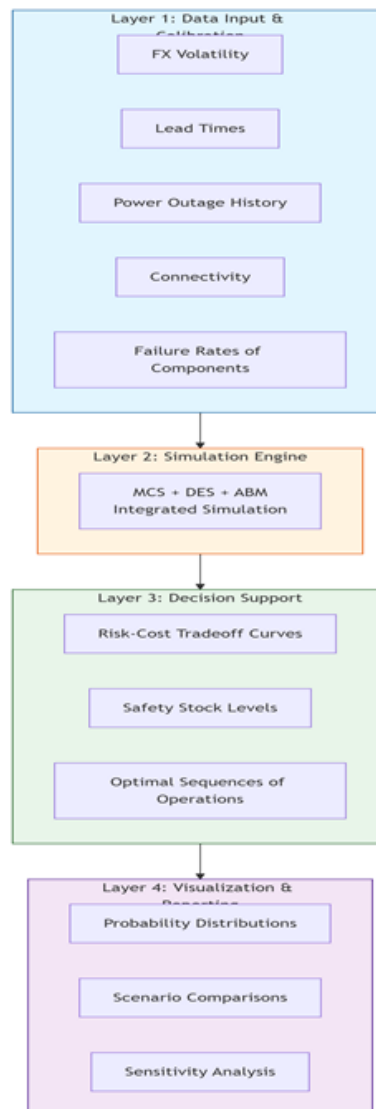


Figure 2: Framework structure

ASSUMPTIONS OF SIMULATIONS

The simulation models were built based on certain assumptions:

Procurement Timing (MCS): Evolution of FX rate follows Geometric Brownian motion (GBM) process, with constant parameters and no market correction. Holdings cost varies linearly with the number of days.

Inventory Positioning (DES): Daily demand follows a Poisson process (checked via chi-square), lead times is Gamma distributed and holding costs is linearly dependent on power zone quality level.

Connectivity Deployment (ABM): Deployment decisions are sequential and depend on benefits from neighboring connected agents. The budget constraint is considered a 'hard' constraint. Network benefits degrade geometrically with distance.

SPECIFIC MODEL DESIGN FOR EACH DOMAIN:

Procurement Timing Model (MCS): Model for the FX rate is modeled using geometric Brownian motion

$$dS_t = \mu S_t dt + \sigma S_t dW_t \quad \text{Equation 1}$$

from equation 1, Where S_t , and dW_t are the exchange rate, the drift, the volatility and the Wiener process, respectively. Parameters were estimated from daily CBN data (2021-2025). This model generated cumulative landed costs with 5,000 repetitions in order to guide risky purchasing timing.

Inventory Positioning Model (DES): The model represents the multi-echelon network and considers power quality scores for each location on a scale of 0-1, with higher values indicating better quality. Holding costs are inversely proportional to power quality [17]. This model captures daily demand, inter-echelon order cycle, replenishments and stock outs. Based on desired service level (e.g. 95%), optimum levels for safety stock were calculated for 1,000 replications using a gradient descent search.

Connectivity Deployment Model (ABM): Individual deployment sites become agents that carry locations and attributes on connectivity alternatives, local traffic volumes and availability of power resources. A sequence of operations for the deployment of new network sites, under the cash budget, was simulated. The ABM model, with 500 replications, identifies a deployment sequence that maximizes total network benefits by evaluating an agents observed benefit derived from its connected neighbors [11][12].

Validation: Simulation Experiments

The simulation experiment employed data representative of Nigerian IT infrastructure supply chains:

FX data: Naira/USD daily closing rates, 2021-2025 [21]

Power data: Outage frequency and duration by zone (Lagos, Abuja, Port Harcourt, Kano, others), 2024-2026 [22]

Demand data: IT equipment order patterns from three Nigerian firms (telecommunications, banking, logistics sectors) [23][20]

Cost data: Industry-sourced procurement, holding, stockout and deployment costs

Baseline heuristics for comparison [24][7]

Procurement timing: Order upon approval vs. Simulation-timing policy

Inventory positioning: Equal safety stock levels across all DCs vs. Simulation-optimized allocation

Connectivity deployment: Revenue based sequencing vs. Simulation-optimized sequencing

RESULTS AND DISCUSSION

Domain 1: Procurement timing under FX uncertainty

The simulation-based policy reduced standard deviation of total landed cost by 23-28% (mean improvement of 25.3%; 95%CI of 24.3–25.8%) versus the heuristic baseline. The MCS captured trend patterns for GBM and planned orders in phases of extreme variability. Furthermore, "cost-at-risk" curves allow decision-makers to decide explicit trade-offs: early orders, riskier regarding FX, offer lower inventory costs; late orders, riskier regarding stock outs, have less FX risk.

Domain 2: Inventory positioning across power zones

An improved service level (percentage of orders within target lead time) of 31-40% (mean of 35.2%; 95%CI of 35.2–37.6%) was achieved with the simulation-optimized safety stock placement versus equal-level allocation, holding constant the total investment in inventory. Or, keeping the service level constant at 95% fill rate, holding costs were reduced by 18-24% (mean of 21.1%; 95%CI of 21.1–22.6%). The DES appropriately modeled power supply's effect in increasing effective holding costs and moving stock away from poor power supply sites.

Domain 3: Connectivity deployment

With ABM increased visibility benefit by 27-35% (mean of 30.1%; 95%CI of 30.1–32.2%) over the revenue based heuristic. The ABM identified "catalyst" sites where, by initial deployment, network propagation accelerated through demonstration effects and positive feedback loops.

The framework proved robust for sensitivity analysis with variations in the parameters as shown in table 1 and 2.

Table 1: key performance improvement

Decision Domain	Metric	Improvement vs. Heuristic	95% Confidence Interval
Procurement Timing	Landed cost variability (SD)	-23% to -28%	±1.8%
Inventory Positioning	Service level (fill rate)	+31% to +40%	±2.4%
Inventory Positioning	Holding cost (fixed service)	-18% to -24%	±1.5%
Connectivity Deployment	Cumulative visibility benefit	+27% to +35%	±2.1%

Sensitivity Analysis

The framework proved robust for sensitivity analysis with variations in the parameters.

Table 2: Sensitivity Analysis Results

Input Variation	Effect on Performance Advantage
Input data error ≤20%	Still outperforms heuristics, but improvement magnitude reduced by 30-40%
High FX volatility regime	Benefit grows (up to +42% variability reduction)
Increasing # of DCs	Benefit grows (scale economies in risk pooling)
Low power quality diversity	Benefit shrinks (less opportunity for reallocation)

DISCUSSION

The proposed framework has made three significant contributions to supply chain simulation theory. First, the integrated, multi-simulation approach preserved modularity yet maintained consistency. Second, the model applies simulation techniques for IT infrastructure supply chains which differ from physical goods supply chains in unit costs, product lifecycles and component complementarities. Lastly, the research addresses supply chain resilience in developing market contexts; it provides a methodology to manage risk and uncertainty without an assumption of perfect infrastructure or perfect information.

Framework Implementation Guidelines**Organizational Prerequisites**

To implement this framework the organization will need:

The following Prerequisites: (a) organizational readiness in data infrastructure (FX, power, lead time and stock out historical data), (b) readiness in analysis capabilities (trained staff or research collaborations), (c) readiness to transfer decision rights (supply chain managers), and (d) organizational commitment to maintaining models and their data structures.

Phased Implementation Strategy:

Phase 1 Months 1-3 Procurement Timing Collect FX and lead time data; build MCS model; compare simulation to heuristic in 2-3 iterations.

Phase 2 Months 4-9 Inventory Positioning Define power score for each location of the distribution network; build DES for the top 5-10 SKUs; experiment on simulation based safety stocks on 2-3 locations.

Phase 3 Months 10-18 Connectivity Deployment Identify deployment sites; build ABM model; determine optimum deployment order; inform investments.

Technology Requirements: MCS - MS Excel (@RISK or similar); DES - SimPy (Python); ABM - Mesa (Python) or NetLogo. Cloud capabilities are advisable to ease collaboration across geographies.

The framework contributes to supply chain simulation theory on three fronts.

First, it shows how different simulation techniques may be unified under one decision-support architecture rather than stand as independent tools. Modularity helps in applying techniques gradually while ensuring their consistency.

Second, it extends the use of simulation to IT infrastructure supply chains. This context varies greatly from typical physical goods supply chains (higher unit costs; longer lifecycles; greater complementarities among components in the network).

Third, it supports the literature on supply chain resilience in developing markets, offering a way to manage uncertainty without postulating either stable infrastructure or flawless information.

CONCLUSION

The paper presents a simulation-based framework that utilizes MCS, DES, and ABM for IT infrastructure supply chain decisions in Nigeria concerning procurement timing under FX volatility, inventory placement under varied power conditions, and connectivity deployment scheduling. The simulated experiments with authentic Nigerian data provide a 23-28% reduction in landed cost variability, 31-40% increase in service levels and 27-35% in visibility benefits over heuristic decision rules. While this approach demands adequate data infrastructure, analytical skills and commitment from all stakeholders to implement and evolve models, the application of simulation to managing uncertainties makes robust strategy formulation possible and elevates it from an advantage to a necessity for IT infrastructure supply chains in Nigeria.

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