



Systems Risk Amplification Model for Geopolitical Disruptions and Cross-Border Public Supply Chain Networks

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Abstract

Geopolitical disruptions increasingly propagate systemic risks across cross-border public supply chain networks, transforming localized shocks into cascading failures with global consequences. Traditional supply chain risk management frameworks often treat disruptions as isolated events, underestimating the nonlinear interactions, feedback loops, and institutional interdependencies that amplify risk across jurisdictions. This review paper introduces a Systems Risk Amplification Model (SRAM) to synthesize and advance existing theoretical and empirical insights on how geopolitical stressors escalate operational, financial, and governance risks within public and quasi-public supply chains. Drawing on systems theory, network science, political economy, and resilience engineering, the paper systematically examines how risk amplification emerges through interlinked mechanisms such as trade policy volatility, sanctions regimes, infrastructure chokepoints, regulatory fragmentation, and information asymmetries. The review maps key amplification pathways across upstream production, cross-border logistics, public procurement systems, and downstream service delivery, emphasizing the role of state actors, multilateral institutions, and critical infrastructure dependencies. Special attention is given to public supply chains supporting essential services, including energy, healthcare, food security, and transportation, where geopolitical shocks have disproportionate societal impacts. By integrating concepts of systemic fragility, adaptive capacity, and institutional coordination, the proposed SRAM framework provides a unifying lens for analyzing risk escalation beyond firm-level exposure. The paper also identifies methodological gaps in current literature, including limited treatment of cross-scale dynamics and insufficient integration of geopolitical indicators into supply chain modeling. The review concludes by outlining future research directions and policy-relevant implications for designing more resilient, geopolitically informed public supply chain networks capable of absorbing and adapting to complex global disruptions (Asuzu *et al.*, 2023).

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1. Introduction

1.1. Background and Motivation

Geopolitical disruptions have become structurally embedded in global economic systems, reshaping the operational stability of cross-border public supply chain networks. Trade sanctions, diplomatic conflicts, regulatory divergence, and infrastructure weaponization increasingly act as systemic shock multipliers rather than isolated stressors. Contemporary supply chains—

particularly those supporting public services such as healthcare, energy, transportation, and food systems—are characterized by dense interdependencies and limited substitutability. As a result, localized geopolitical events can propagate rapidly across jurisdictions, triggering cascading failures that overwhelm traditional risk mitigation mechanisms. These dynamics expose the inadequacy of linear risk models that assume independence among supply chain nodes and predictability in state behavior (Olagoke *et al.*, 2023; Dada *et al.*, 2021b).

The motivation for this review arises from the growing recognition that supply chain resilience cannot be divorced from geopolitical context. Network-based disruption forecasting studies demonstrate that geopolitical risks amplify through structural bottlenecks, information asymmetries, and policy feedback loops embedded within international supply systems (Nwabueze *et al.*, 2022). Public supply chains are particularly vulnerable due to rigid procurement frameworks, sovereignty-driven policy constraints, and reliance on cross-border coordination among state and quasi-state actors. Risk management research in international business further highlights how geopolitical uncertainty alters decision horizons, investment flows, and governance arrangements, increasing systemic exposure rather than merely operational risk. These realities necessitate a systems-level analytical framework capable of explaining how geopolitical disruptions escalate into systemic supply chain crises (Thai, 2017; Bamgboye *et al.*, 2019; Isiekwu, 2022).

1.2. Contributions to Supply Chain and Geopolitical Risk Literature

This review contributes to supply chain and geopolitical risk scholarship by advancing a systems-oriented perspective that bridges operational, institutional, and geopolitical domains. Existing supply chain literature often emphasizes efficiency optimization, procurement cost control, and digital integration while treating geopolitical conditions as exogenous variables. Comparative procurement studies across jurisdictions reveal that public supply chains operate under heterogeneous regulatory and political constraints that directly influence risk exposure and response capacity. However, such studies rarely conceptualize how these constraints interact dynamically during geopolitical crises. This review addresses that gap by reframing procurement, logistics, and governance structures as endogenous components of risk amplification processes (Okonkwo *et al.*, 2018; Okonkwo *et al.*, 2019; Isiekwu, 2023).

The paper further contributes by synthesizing digital systems engineering and real-time risk analytics with geopolitical risk analysis. Integrated IT-supply chain frameworks demonstrate how digital interconnectivity enhances visibility but simultaneously increases systemic fragility when exposed to cross-border political shocks (Okonkwo *et al.*, 2023). Evidence from public sector supply chains, particularly healthcare systems, shows that machine-learning-driven dashboards improve situational awareness but remain constrained by upstream geopolitical dependencies such as import restrictions, diplomatic tensions, and regulatory fragmentation (Filani *et al.*, 2022). By unifying these strands, the review extends existing literature beyond firm-centric resilience toward a multi-scalar systems risk amplification model that explicitly incorporates geopolitical triggers,

institutional coordination failures, and network-level feedback mechanisms (Olamide & Badmus, 2021; Ugwu-Oju *et al.*, 2021; Isiekwu *et al.*, 2025; Oluwo *et al.*, 2024).

1.3. Scope and Objectives of the Review

This review focuses on cross-border public supply chain networks operating within geopolitically volatile environments, emphasizing systems-level risk amplification rather than isolated disruption events. The scope encompasses supply chains that support essential public and quasi-public services, including healthcare delivery systems, energy infrastructure, food distribution networks, and transportation logistics. These systems are examined not only as operational constructs but as socio-technical networks shaped by policy regimes, international relations, and institutional coordination mechanisms. The review deliberately excludes firm-level tactical risk mitigation strategies unless they contribute directly to understanding systemic propagation effects across borders (Okeke *et al.*, 2019; Nwankwo *et al.*, 2020; Nwankwo *et al.*, 2022; Isiekwu, 2025b).

The primary objective of the review is to develop a coherent Systems Risk Amplification Model that synthesizes fragmented insights from supply chain resilience, geopolitical risk analysis, and systems engineering. Specifically, the review seeks to identify dominant amplification pathways through which geopolitical disruptions escalate across interconnected supply networks, to clarify the role of public governance structures in mediating or intensifying risk, and to evaluate existing analytical approaches used to model cascading disruptions. By consolidating these objectives, the paper aims to provide a structured analytical foundation for future empirical modeling, policy design, and cross-border coordination strategies in public supply chain systems (Kshetri, 2018; Seyi-Lande *et al.*, 2019; Jinadu *et al.*, 2023; Uduokhai *et al.*, 2023; Isiekwu, 2025a).

1.4. Structure of the Paper

The paper is structured to progress logically from foundational theory to applied systems analysis. Following the introduction, the second section establishes the conceptual underpinnings of systems risk within complex supply chain networks, drawing on systems theory and network dynamics to explain how interdependencies shape vulnerability. The third section examines geopolitical disruptions as external but structurally embedded risk catalysts, analyzing how trade policies, sanctions, and political instability interact with supply chain architectures (Borgatti *et al.*, 2018).

The fourth section introduces the Systems Risk Amplification Model, detailing its components, feedback mechanisms, and institutional dimensions. This section serves as the analytical core of the paper, integrating insights from preceding sections into a unified framework. The fifth section explores the practical implications of the model for cross-border public supply chain resilience, with particular attention to policy coordination, digital infrastructure, and governance alignment. The final section outlines future research directions, emphasizing methodological advancements and interdisciplinary integration necessary to operationalize systems-based geopolitical risk analysis in public supply networks (Tang & Musa, 2014; Tang *et al.*, 2018).

2. Conceptual Foundations of Systems Risk in Supply Chains

2.1. Systems Theory and Complex Adaptive Networks

Systems theory provides a foundational lens for understanding cross-border public supply chains as complex adaptive networks characterized by interdependence, feedback loops, and emergent behavior. Rather than operating as linear sequences of transactions, public supply chains evolve through continuous interaction among technological systems, institutional actors, and geopolitical constraints. Digital transformation studies demonstrate that system performance is shaped by dynamic alignment between infrastructure elasticity, governance logic, and decision latency, reinforcing the view of supply chains as adaptive socio-technical systems rather than static pipelines (Adesanya *et al.*, 2022; Bayeroju, 2023). Within such systems, local optimization often produces global instability when coordination thresholds are breached (Kettl, 2015; Choi *et al.*, 2016; Badmus & Olamide, 2020).

Complex adaptive network behavior is further amplified by embedded intelligence layers such as predictive analytics, AI governance indices, and real-time dashboards, which alter feedback velocities and decision coupling across borders (Aifuwa *et al.*, 2020). Empirical frameworks demonstrate that visibility architectures and asset lifecycle integration introduce both resilience and fragility by tightening inter-node dependencies (Okonkwo *et al.*, 2023). In public systems, this duality is pronounced due to regulatory rigidity and sovereign control over nodes such as ports, energy corridors, and procurement platforms (Ijiga *et al.*, 2022; Ekechi & Fasasi, 2022). Consequently, systems theory reframes geopolitical disruption not as an external shock but as an endogenous stressor capable of reconfiguring network behavior once adaptive limits are exceeded (Hearnshaw &

Wilson, 2016; Anichukwueze *et al.*, 2021).

2.2. Risk Propagation and Nonlinear Dynamics

Risk propagation in cross-border public supply chains exhibits fundamentally nonlinear behavior driven by delayed feedback, compounding dependencies, and institutional coupling. Unlike proportional risk escalation assumed in traditional models, empirical evidence across financial systems, healthcare networks, and infrastructure operations demonstrates threshold-based transitions where minor disruptions trigger disproportionate systemic effects (Farounbi *et al.*, 2021; Dako *et al.*, 2021). These nonlinearities are intensified by digital intermediation layers that accelerate information flow while simultaneously increasing coupling density (Obuse *et al.*, 2020; Oduleye & Medon, 2021; Olatunji *et al.*, 2021; Dada *et al.*, 2021a).

In public supply systems, nonlinear risk amplification manifests through cascading failures across governance, logistics, and service delivery. For instance, disruptions in upstream regulatory approvals can propagate into healthcare access breakdowns despite intact physical supply capacity (Oparah *et al.*, 2021). Machine-learning-based fault forecasting in energy and subsea systems further illustrates how early-stage anomalies evolve into system-wide outages when feedback loops are misaligned. Environmental compliance failures in multi-stakeholder projects similarly demonstrate how institutional lag amplifies operational risk beyond controllable limits (Badmus & Olamide, 2023) as seen in Table 1. These dynamics underscore the necessity of modeling geopolitical disruptions as nonlinear processes embedded within public supply chain architectures rather than isolated operational shocks (Agbabiaka *et al.*, 2019; Olamide & Badmus, 2021; Omolayo *et al.*, 2022; Isiekwu, 2024).

Table 1: Summary of Risk Propagation and Nonlinear Dynamics in Cross-Border Public Supply Chains

Dimension of Risk Propagation	Underlying Nonlinear Mechanism	Manifestation in Public Supply Chains	Systemic Implications
Delayed feedback and threshold effects	Time-lagged institutional responses and policy approval cycles create nonlinear escalation once critical thresholds are crossed	Minor regulatory or diplomatic delays cascade into widespread service interruptions despite available physical resources	Sudden transition from stable operation to systemic disruption, reducing the effectiveness of incremental mitigation measures
Compounding interdependencies	High coupling density across logistics, governance, and digital systems amplifies small disturbances	Disruptions propagate simultaneously across procurement, distribution, and service delivery layers	Increased vulnerability to cascading failures that exceed the control capacity of individual agencies
Digital intermediation acceleration	Real-time data flows and automated decision systems intensify feedback speed and coupling	Rapid propagation of risk signals across borders and institutions without corresponding adaptive safeguards	Amplification of systemic risk due to synchronization of failures rather than containment
Institutional and governance lag	Misalignment between operational signals and policy or compliance actions	Early-stage anomalies evolve into large-scale outages in energy, healthcare, and infrastructure systems	Loss of controllability as governance delays magnify operational instability and societal impact

2.3. Public versus Private Supply Chain Risk Characteristics

Public and private supply chains differ fundamentally in their exposure, response capacity, and risk amplification pathways. Private supply chains prioritize efficiency, speed, and shareholder value, enabling rapid reconfiguration under geopolitical stress through contractual renegotiation or supplier substitution. In contrast, public supply chains are constrained by statutory procurement rules, accountability mandates, and political oversight, which significantly slow adaptive response during crises (Akinola *et al.*, 2020). These structural rigidities increase susceptibility to geopolitical

shocks, particularly in essential service domains such as healthcare, energy, and transportation (Aminu-Ibrahim *et al.*, 2020; Yeboah & Ike, 2020; World Bank, 2019).

Digitalization further accentuates these differences. While private systems leverage cloud elasticity and predictive scaling to absorb volatility (Ahmed *et al.*, 2020), public systems often operate hybrid or legacy architectures that amplify failure propagation once stressed (Ugwu-Oju *et al.*, 2022). The integration of IoT and digital twins improves transparency but simultaneously exposes public networks to systemic cyber and governance risks absent in private contexts (Sanusi *et al.*, 2023). Moreover, public supply

chains must balance socioeconomic equity, compliance, and service continuity, introducing risk trade-offs not present in profit-oriented systems (Ogbete *et al.*, 2020; Omotayo *et al.*, 2020). These distinctions reinforce the necessity of treating public supply chains as unique systemic entities requiring specialized geopolitical risk frameworks rather than adaptations of private-sector models (Ahmed & Odejebi, 2018; Olatunde *et al.*, 2022).

3. Geopolitical Disruptions as Risk Catalysts

3.1. Trade Conflicts, Sanctions, and Regulatory Fragmentation

Trade conflicts and sanctions operate as first-order geopolitical shocks that fragment regulatory alignment across cross-border public supply chains. Sanction regimes disrupt procurement legality, contract enforceability, and supplier eligibility, introducing compliance risk into otherwise operationally viable supply networks (Adesanya *et al.*, 2022; Dako *et al.*, 2021). Regulatory fragmentation intensifies when divergent national responses to sanctions generate incompatible customs rules, licensing requirements, and audit standards, thereby amplifying transactional friction across borders (Sanni *et al.*, 2020). These dynamics undermine the assumption of regulatory continuity embedded in many public procurement frameworks, particularly those designed for multilateral cooperation (Ijiga *et al.*, 2022; Power, 2016; Heald, 2018) (Oyeleye *et al.*, 2023a).

From a systems perspective, sanctions-driven trade conflicts propagate risk through networked dependencies rather than discrete supply interruptions. Network analytics research demonstrates that supplier exclusion cascades downstream, constraining inventory replenishment, inflating compliance overheads, and delaying public service delivery timelines (Nnabueze *et al.*, 2022; Aifuwa *et al.*, 2020). Digital integration further compounds vulnerability, as compliance automation systems must rapidly reconfigure rulesets to reflect shifting geopolitical mandates (Okonkwo *et al.*, 2023). Empirical resilience studies reveal that public supply chains lacking adaptive regulatory intelligence experience prolonged recovery periods following sanction-induced disruptions (Bayeroju, 2023). Consequently, trade conflicts function not merely as economic barriers but as systemic risk accelerants embedded within governance and information infrastructures (Yeboah & Ike, 2023; Olatunde-Thorpe *et al.*, 2020; Williamson, 2014; Ugwu-Oju *et al.*, 2018; Badmus & Olamide, 2019).

3.2. Infrastructure Chokepoints and Strategic Dependencies

Infrastructure chokepoints constitute structural vulnerabilities where geopolitical disruptions convert physical constraints into systemic supply chain failures. Strategic dependencies on ports, pipelines, rail corridors, and digital logistics platforms concentrate risk within narrow nodes that lack redundancy (Patrick *et al.*, 2020). When geopolitical tensions intersect with these chokepoints, public supply chains experience nonlinear disruption patterns, particularly in sectors dependent on continuous material flows such as energy, healthcare, and food systems (Aminu-Ibrahim *et al.*, 2020; Filani *et al.*, 2022). Infrastructure risk assessments increasingly demonstrate that chokepoint failure propagates simultaneously across multiple public services rather than sequentially (Ofoedu *et al.*, 2023; Oguniola *et al.*, 2021; Isiekwu *et al.*, 2021).

Strategic dependency deepens when infrastructure governance is fragmented across jurisdictions with misaligned security priorities and investment incentives. Systems engineering studies reveal that digital and physical infrastructure co-dependencies magnify exposure to cyber-physical disruptions during geopolitical crises (Obuse *et al.*, 2020). Environmental compliance and sustainability mandates further constrain infrastructure flexibility, limiting rapid rerouting or capacity expansion during crises (Badmus & Olamide, 2023; Nduka, 2022). Public-sector planning frameworks that fail to incorporate geopolitical stress testing inadvertently reinforce fragility by optimizing for efficiency over resilience. Consequently, infrastructure chokepoints function as systemic amplifiers rather than passive bottlenecks, reinforcing the necessity of integrated risk governance across strategic assets (Ekechi & Fasasi, 2022; Yeboah & Ike, 2020; Moore, 2018; Anichukwueze *et al.*, 2019).

3.3. Political Instability and Cross-Border Coordination Failures

Political instability introduces coordination failures that disrupt the institutional glue binding cross-border public supply chains. Regime changes, governance breakdowns, and policy reversals undermine treaty enforcement, data-sharing agreements, and procurement harmonization mechanisms (Farounbi *et al.*, 2021; Sanusi *et al.*, 2021). These disruptions disproportionately affect public supply chains, which rely on bureaucratic continuity and multilateral coordination rather than market-driven adaptability (Ijiga *et al.*, 2022; Elebe & Imediegwu, 2021). Empirical governance studies demonstrate that coordination breakdowns often precede material shortages, indicating that institutional failure is an early-stage amplifier of systemic risk (Nwankwo *et al.*, 2021; Kyere Yeboah *et al.*, 2019; Elebe & Imediegwu, 2023).

Cross-border coordination failures are further intensified by information asymmetry and decision latency during political crises. Public-sector digital platforms designed for transparency and compliance frequently lack interoperability across jurisdictions, delaying synchronized responses (Moyo *et al.*, 2021). In politically unstable environments, fragmented leadership structures inhibit rapid consensus-building, forcing supply chains into reactive rather than anticipatory modes (Pamela *et al.*, 2021). Health and social service supply chains are particularly vulnerable, as coordination lapses directly translate into service delivery failures (Oparah *et al.*, 2021). From a systems perspective, political instability transforms coordination failure into a self-reinforcing loop, where governance erosion accelerates operational collapse across borders (Badmus & Olamide, 2021; Succar, 2017; Whyte & Hartmann, 2017; Love *et al.*, 2019).

4. Systems Risk Amplification Model (SRAM)

4.1. Core Components and Amplification Mechanisms

The Systems Risk Amplification Model identifies core components through which geopolitical disruptions intensify across cross-border public supply chains. Central to this framework is structural interdependence, whereby procurement, logistics, regulatory oversight, and information systems are tightly coupled across national boundaries. Empirical supply chain analytics demonstrate that efficiency-oriented designs—such as centralized sourcing, minimal

buffer inventories, and synchronized production—act as latent amplifiers when exposed to geopolitical shocks (Aifuwa *et al.*, 2020). Trade restrictions, sanctions, or border closures disrupt not only material flows but also financial settlements, compliance verification, and data exchange architectures embedded within public procurement systems (Farounbi *et al.*, 2018; Okeke *et al.*, 2023; Oluwo *et al.*, 2022) (Oyeleye *et al.*, 2024).

Amplification mechanisms further emerge from digital and institutional concentration risks. AI-enabled supply chain optimization frameworks improve visibility under stable conditions but accelerate failure propagation when upstream geopolitical constraints invalidate predictive assumptions (Bayeroju, 2023; Okonkwo *et al.*, 2023). Studies on governance risk indexing and compliance automation illustrate how regulatory divergence and jurisdictional conflicts compound delays, especially in public-sector contracting and essential services provisioning (Dako *et al.*, 2021). Infrastructure-dependent sectors such as energy and healthcare exhibit particularly high amplification sensitivity due to capital intensity and limited substitutability (Ofoedu *et al.*, 2023; Ogunsola & Michael, 2023). Systems-level land-use and infrastructure planning analyses further confirm that geopolitical disruptions magnify spatial vulnerabilities embedded in public asset configurations (Ijiga *et al.*, 2022; Ekechi & Fasasi, 2022). Collectively, these components establish amplification as an emergent system property rather than a sequence of isolated operational failures (Wieland & Wallenburg, 2016; Odejebi & Ahmed, 2018).

4.2. Feedback Loops, Thresholds, and Cascading Effects

Risk amplification within cross-border public supply chains is sustained through reinforcing feedback loops that accelerate disruption beyond critical thresholds. Financial stress propagation models show that minor trade interruptions trigger liquidity constraints, delayed payments, and covenant breaches that recursively weaken supplier viability and public procurement capacity (Adesanya *et al.*, 2022; Farounbi *et al.*, 2021). These financial feedbacks interact with digital infrastructure dependencies, where cloud-based coordination systems propagate latency and data inconsistency during jurisdictional access restrictions (Ahmed *et al.*, 2020; Obuse *et al.*, 2020). Once these systems exceed operational tolerance thresholds, cascading effects become irreversible without external intervention (Kraljic, 2018).

Threshold dynamics are particularly visible in public health, food security, and energy supply systems. Predictive modeling of population-level service delivery demonstrates how marginal supply delays amplify into systemic access failures when institutional response capacity is exceeded (Gado *et al.*, 2020; Pamela *et al.*, 2021). Agricultural and infrastructure studies further indicate that environmental, spatial, and logistical constraints interact with geopolitical stressors to produce nonlinear escalation patterns (Aminu-Ibrahim *et al.*, 2020; NDUKA, 2022). Governance delays and fragmented communication compound these effects, as illustrated by digital service support and endpoint security research in public-sector information systems (Nwankwo *et al.*, 2021). The resulting cascades extend beyond operational domains, affecting workforce stability, public trust, and policy credibility (Ogbete *et al.*, 2020; Nwafor *et al.*, 2020). These findings affirm that feedback-driven escalation, rather than initial shock magnitude, determines systemic collapse in geopolitically stressed supply networks (Koppenjan & Klijn,

2016; Eastman *et al.*, 2018; Ogunsola *et al.*, 2021).

4.3. Institutional and Governance Dimensions of Amplification

Institutional and governance structures play a decisive role in transforming geopolitical disruptions into system-wide supply chain failures. Fragmented regulatory authority, misaligned procurement mandates, and jurisdiction-specific compliance regimes introduce coordination delays that amplify disruption intensity (Dako *et al.*, 2021). Studies on port logistics, ERP procurement, and demurrage elimination demonstrate how institutional bottlenecks convert policy uncertainty into operational paralysis (Agbabiaka *et al.*, 2020; Patrick *et al.*, 2020). These effects are magnified in public supply chains where legal rigidity constrains adaptive reconfiguration during geopolitical crises (Okonkwo *et al.*, 2020; Sanni & Adumaza, 2023).

Governance-driven amplification is further reinforced by digital policy misalignment and leadership fragmentation. Research on cloud governance, executive decision dashboards, and compliance monitoring reveals that centralized oversight without cross-border interoperability exacerbates information asymmetry and response lag (Filani *et al.*, 2022; Sanni & Atima, 2021). Workforce capability gaps and leadership discontinuities compound these risks, particularly in technologically mediated public services (Ugwu-Oju *et al.*, 2022). Environmental and agricultural governance studies also highlight how delayed institutional coordination accelerates service degradation in essential supply systems (Oyeboade & Olagoke-Komolafe, 2022). Infrastructure governance failures—spanning energy, transportation, and telecommunications—ultimately transform geopolitical stress into structural instability (Oziri *et al.*, 2022; Ayanbode *et al.*, 2021) as seen in Table 2. By situating governance as an endogenous amplification driver, this section underscores the necessity of institutional redesign for mitigating systemic geopolitical supply chain risk (Helbing, 2013; Okojie *et al.*, 2023).

Table 2: Institutional and Governance Drivers of Risk Amplification in Cross-Border Public Supply Chains

5. Implications for Cross-Border Public Supply Chain Resilience

5.1. Critical Public Sectors and Essential Services

Critical public sectors such as healthcare, energy, food systems, transportation, and water infrastructure represent the most sensitive nodes within cross-border public supply chain networks. These sectors exhibit high demand inelasticity, low tolerance for disruption, and strong dependence on international sourcing and regulatory coordination. Empirical studies of healthcare and food systems demonstrate how disruptions propagate rapidly when upstream dependencies intersect with constrained public procurement rules and limited substitution capacity (Ejairu *et al.*, 2022). Environmental and public-health risk analyses further show that disruptions in essential supply inputs can translate directly into population-level welfare losses, amplifying political and social instability (Agyemang *et al.*, 2022; Pamela *et al.*, 2021; Hood & Dixon, 2015; Aminu-Ibrahim *et al.*, 2019; Olamide & Badmus, 2020).

From a systems perspective, public supply chains supporting essential services are structurally predisposed to risk amplification because governance, infrastructure, and service delivery functions are tightly coupled. Digital integration and

operational visibility frameworks improve monitoring but also introduce systemic fragility when geopolitical shocks disrupt shared platforms or cross-border data flows (Okonkwo *et al.*, 2023; Sanusi *et al.*, 2023). Research on public-sector resilience emphasizes that essential services often rely on a narrow set of international suppliers and logistics corridors, making them particularly vulnerable to sanctions, export controls, and diplomatic breakdowns (Ofoedu *et al.*, 2023). These dynamics underscore the need for systems-level risk assessment approaches that move beyond sector-specific resilience toward integrated geopolitical exposure analysis (Ijiga *et al.*, 2023; Yeboah & Ike, 2023; Badmus & Olamide, 2023; Mergel, 2019).

5.2. Risk Mitigation, Adaptive Capacity, and Policy Coordination

Risk mitigation in geopolitically exposed public supply chains depends fundamentally on adaptive capacity and cross-jurisdictional policy coordination. Traditional mitigation strategies that emphasize inventory buffers or supplier diversification are insufficient when geopolitical shocks simultaneously disrupt trade policy, financial flows, and regulatory alignment. Studies on public-sector analytics and financial governance highlight the importance of anticipatory risk frameworks that integrate institutional behavior, policy lag effects, and multi-actor coordination mechanisms into decision-making processes (Dako *et al.*, 2021). Without such integration, risk mitigation efforts remain reactive and fragmented, increasing the likelihood of systemic escalation (Ansell & Torfing, 2017; Anichukwueze *et al.*, 2021) (Oyeleye *et al.*, 2023b).

Adaptive capacity is enhanced when policy instruments, digital infrastructure, and organizational learning mechanisms operate coherently across borders. Research on digital transformation and regulatory automation shows that adaptive public systems rely on real-time intelligence, standardized compliance frameworks, and interoperable governance architectures (Bayeroju, 2023). However, policy coordination failures often undermine these capabilities, particularly when geopolitical tensions introduce regulatory asymmetries and conflicting national priorities (Nduka, 2022; Akinola *et al.*, 2020). Systems-level analyses emphasize that adaptive capacity is not merely a technical attribute but an institutional one, shaped by leadership alignment, workforce capability, and policy coherence (Ijiga *et al.*, 2022; Yeboah & Ike, 2020). Integrating these dimensions enables public supply chains to absorb shocks without triggering cascading failures (Filani *et al.*, 2022; Jordan *et al.*, 2015; Kane *et al.*, 2018; Ogunsola & Michael, 2021; Sanni *et al.*, 2023) (Eyetsemitan *et al.*, 2022).

5.3. Integrating Geopolitical Indicators into Supply Chain Planning

Integrating geopolitical indicators into public supply chain planning represents a critical advancement beyond conventional operational forecasting. Existing planning models emphasize demand variability, cost optimization, and logistics efficiency while excluding political volatility, regulatory friction, and diplomatic risk signals. Studies on predictive analytics and digital infrastructure demonstrate that planning accuracy improves when external risk indicators are incorporated into scenario modeling and early-warning systems (Ahmed *et al.*, 2020). Geopolitical indicators such as trade policy volatility, sanctions exposure,

and cross-border compliance divergence can be operationalized through composite risk indices embedded within planning dashboards (Christopher, 2016; Olamide & Badmus, 2019; Kyere Yeboah *et al.*, 2021; Okojie *et al.*, 2023).

Technical frameworks for integration increasingly rely on data fusion architectures that combine geopolitical intelligence with supply chain telemetry. Research on cloud-based analytics and digital twins illustrates how real-time data ingestion enables planners to simulate geopolitical shock scenarios and assess downstream impacts across public service delivery systems (Patrick *et al.*, 2020). Infrastructure and facility planning studies further highlight how geopolitical foresight improves resilience by guiding strategic asset placement, redundancy investment, and supplier qualification decisions (Ogbete *et al.*, 2020). Embedding geopolitical indicators within planning systems transforms public supply chains from reactive entities into anticipatory systems capable of mitigating risk amplification before disruption cascades occur (Oziri *et al.*, 2020; Nwankwo *et al.*, 2021; Alford & O'Flynn, 2017; Seyi-Lande *et al.*, 2020) (Ibeh *et al.*, 2023).

6. Future Research Directions and Conclusions

6.1. Methodological Gaps and Emerging Research Opportunities

Current methodological approaches to studying geopolitical disruptions in cross-border public supply chain networks remain fragmented and insufficiently systemic. A dominant limitation lies in the continued reliance on static or linear modeling techniques that fail to capture nonlinear feedback loops, threshold effects, and time-dependent escalation pathways inherent in geopolitical crises. Many existing models prioritize firm-level resilience metrics or localized disruption scenarios, overlooking how risk propagates across institutional layers such as customs authorities, public procurement agencies, multilateral regulators, and sovereign infrastructure operators. This methodological reductionism obscures the mechanisms through which minor political shocks escalate into systemic failures affecting multiple jurisdictions simultaneously (Ponomarov & Holcomb, 2017; Ayanbode *et al.*, 2019).

Emerging research opportunities lie in the integration of multi-layer network modeling, dynamic systems simulation, and scenario-based stress testing tailored to public supply chains. Future studies should incorporate endogenous geopolitical variables, such as policy volatility indices, sanction cascades, and diplomatic coordination delays, directly into supply chain risk models rather than treating them as external shocks. Agent-based modeling and digital twin architectures present promising avenues for simulating cross-border risk amplification under competing political and operational constraints. Additionally, there is a need for longitudinal datasets that track institutional responses, regulatory adaptations, and infrastructure reconfiguration during prolonged geopolitical disruptions. Advancing methodological rigor in this direction would enable more accurate prediction of cascading failures and support the development of anticipatory governance mechanisms for public supply networks (Ansell & Torfing, 2016; Floridi *et al.*, 2018; Sanni *et al.*, 2022; Dada *et al.*, 2024).

6.2. Policy and Managerial Implications

The findings of this study carry significant implications for

policymakers and public-sector supply chain managers operating in geopolitically exposed environments. From a policy perspective, the Systems Risk Amplification Model highlights the inadequacy of siloed regulatory frameworks that prioritize national resilience without accounting for transboundary interdependencies. Effective risk mitigation requires coordinated policy instruments that align trade regulations, emergency procurement protocols, and information-sharing mechanisms across borders. Governments must move beyond reactive crisis management toward anticipatory governance structures capable of identifying amplification thresholds before disruptions escalate into systemic breakdowns (Walker *et al.*, 2014; Radin, 2017) (Dogbatsey *et al.*, 2026).

For managers of public and quasi-public supply chains, the implications are equally profound. Traditional performance optimization strategies focused on cost efficiency and just-in-time delivery increase exposure to geopolitical shocks by reducing redundancy and adaptive capacity. Managerial decision-making must therefore incorporate geopolitical stress indicators into procurement planning, supplier diversification strategies, and infrastructure investment decisions. For example, reliance on a single geopolitical corridor for critical medical supplies may appear efficient under stable conditions but becomes a liability during diplomatic conflicts or sanctions. Embedding systems risk analytics into operational dashboards, contingency planning, and cross-agency coordination protocols can significantly enhance resilience. Ultimately, aligning managerial practices with systems-level risk awareness enables public supply chains to function as stabilizing institutions rather than amplifiers of geopolitical instability (Ivanov *et al.*, 2014; Flynn *et al.*, 2017; Nwafor *et al.*, 2019; Ike *et al.*, 2022) (Oyeleye *et al.*, 2022) (Oyeleye *et al.*, 2025).

6.3. Concluding Remarks

This study advances the understanding of geopolitical disruptions by reframing cross-border public supply chains as complex systems prone to risk amplification rather than isolated operational failures. The Systems Risk Amplification Model developed in this review provides a structured lens for analyzing how political, institutional, and infrastructural factors interact to escalate disruptions across interconnected networks. By synthesizing insights from systems theory, network dynamics, and public-sector supply chain governance, the study demonstrates that geopolitical risk is not merely an external disturbance but a structurally embedded property of contemporary global supply systems. The broader implication of this work is a call for a paradigm shift in how public supply chain resilience is conceptualized and operationalized. Resilience must be understood as an emergent system characteristic shaped by governance alignment, information flow integrity, and adaptive coordination across borders. Addressing geopolitical risk therefore requires integrated analytical frameworks and institutional reforms that transcend organizational and national boundaries. By articulating these dynamics, this study lays a foundation for more robust empirical research, informed policy design, and strategic public-sector management capable of navigating an increasingly volatile geopolitical landscape without triggering systemic supply chain failures (Eyetsemitan *et al.*, 2023).

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