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Research Paper

Resilience and efficiency in global supply chains: a strategic framework for disruption management

Mustafa Musa*
*Centre for Research and Innovation Management, Universiti, Teknikal, Melaka, Malaysia.

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ABSTRACT

Efficiency-focused global supply chains have been found to be all too susceptible to disruptions and disruptions of growing scale and frequency such as pandemics, geopolitical conflicts, natural disasters and cyber-attacks. The COVID-19 pandemic specifically revealed the systemic vulnerabilities of lean, remotely spread supply chains, forcing companies to address the efficiency-dominated paradigm archetype roots radically. In this study, a systematic evidence-based strategic model of managing supply chain disruption is proposed and confirmed through empirical research, consists of seven pillars whereby resilience-based abilities and operation-clean efficiency requirements are linked. A mixed-method research design was to be used that incorporated the structured survey of 243 Asian, Middle Eastern and European supply chain professionals working in the manufacturing, retail, pharmaceutical and logistics industry segment with 6 in-depth organizational case studies. Causal relationships were examined by structural equation modelling (SEM) to understand the relationship between the framework pillars and performance results of the supply chain. The seven pillars of the supposed structure are: (i) end-to-end supply chain visibility through IoT and block chain solutions, (ii) supplier diversification and near shoring, (iii) AI-based demand sensing and foreseeing, (iv) strategic inventory buffering, (v) agile and flexible production capacity, (vi) digital twin enabled scenario-modelling and (vii) continuing to collaborate between organizations. Empirical estimates indicate that companies that have attained complete framework implementation have noted a drop of 60.5 percent in mean supply chain recuperation time, 18-percentage-point rise in on-time in-full conveyance rate, a margin of 52.2 percent cut to supplier risk assessment scores and 19% drop in cost-to-serve introduction. The analysis introduces a theoretically insightful and practically implementable framework that will allow leaders in supply chains to build resilience in a systematic and efficiency-saving manner. Managerial suggestions to order of implementation and policy implications to supply chain risk governance.

Corresponding Author:
Mustafa Musa
Centre for Research and Innovation Management, Universiti, Teknikal, Melaka, Malaysia.
Email: mustafamusa@utem.edu.my

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1. INTRODUCTION

Convincingly, global supply chains have been designed based on economics of scale, efficient management of inventory, as well as geographic specialization brought about by globalization [1]. During some decades, this paradigm provided strong economic benefits: companies sourced at the cheapest points in the world, maintained low buffer stocks and had a just-in-time factory system that was tuned to predictability. Nevertheless, a series of much bigger disruptions has revealed the brittle nature inherent in this optimization of efficiency model in a more systematic way [2].

The 2020 COVID-19 pandemic caused a clean and massive demand shock and supply shock in virtually every industry of the world [3]. The closure of Asian factories destabilized the supply of parts to the upstream supply chain, measures in ports and container shortages crippled ocean freight chains and customer behavior reacted unexpectedly and delays in demand as more people stayed at home and new markets reacted to workplace restrictions and lockdowns. Those semiconductor, pharmaceutical and medical equipment and consumer goods shortages demonstrated how low redundancy, close-knit supply chains could prove more susceptible to the effect of disruptions on the system rather than neutralizing them. Companies that had diversified supplier, digital visibility infrastructure and responsive state of manufacturing proved to be better than those who ran lean, single-source, visibility-blind networks [4].

Supply chain resilience has therefore transformed its peripheral position to be at the core of supply chain strategy. The general definition of supply chain resilience is the ability of a supply chain to react to adequate capacity of unexpected disruption, reaction to this and restore to the initial or preferred level of operations without victimizing continuity of operations, long term competitive advantage [5]. Nevertheless, literature in academia and practice provides their guidance on how to achieve resilience in a methodic fashion, at the same time maintaining operational efficiency, a tension that was recognized as major strategic issue faced by the supply chain managers [6].

This paper fills the gap by establishing and empirically demonstrating a seven pillar strategic framework of managing supply chain disruptions. The framework summarizes the evidence-based resilience mechanisms into systematic approachable model to use in the industry sectors simultaneously. The inquiry is directed by three research questions as follows: (RQ1) what typology of disruptions has the most substantial impact on global supply chain continuity and performance? (RQ2) What are the strategic capabilities as the pillars of resilient and an efficient supply chain? (RQ3) What are the quantifiable performance outcomes of (the proposed) framework adoption? This paper is structured into the following sections: Section 2 provides a review of the available literature, Section 3 outlines the research methodology, Section 4 will state and discuss the empirical results and finally Section 5 will provide a conclusion of the study in relation to theoretical background and managerial implications as well as suggestions on future research work.

2. RELATED WORK

Supply chain resilience building on researches in systems theory, organizational resilience theory and resource-based view of the firm are conceptually grounded [7]. Among the first to introduce a

definition of the management construct of supply chain resilience, Christopher and Peck recognized four building blocks, one is supply chain re-engineering and another is supply chain collaboration, the third is agility and the fourth is a risk management culture [8]. Their model provided the initial basis of the fact that resilience is not a single competence but a portfolio of adaptive competencies in a multidimensional form.

Efficiency-resilience tension is a structural issue recognized within the area of supply chain management. Tang has led a powerful review that has found eight supply chain strategies that are robust, such as flexible supply base, postponement and economic supply incentives, capable of maximizing efficiency and resilience at the same time [9]. Empirically showed supply chain vulnerability depends on the probability to be disrupted and the color of operational impact, proposing a risk matrix viewpoint to help specify better investments on resilience [10]. Still more recently, have proposed that the classical robustness elementary-agility-resilience model should be combined to include recoverability and adaptability as additional dimensions in the wake of pandemic-scale systemic swamping's [11].

Supply chain visibility has become one of the most essential preconditions of positive disruption response. Established based on survey research that proactive supply chain risk management and reactive supply chain agility are both found to be highly mediated by inter-organizational information sharing and visibility [12]. With the introduction of block chain, supply chain control towers using IoT sensors and clouds, the technical ability of firms to attain a real-time end-to-end visibility in the multi-tier supplier networks has been significantly increased [13].

Of group interest since 2020 has been increased scholarly and practitioner interest in supplier diversification and near shoring strategies. Securing carried out a systematic review of 93 articles on supply chain risk management and established the fact that multi-sourcing and supplier base diversification are among the best-studied resilience options, their effectiveness however needs to be well-managed [14]. Coined the opinion of supply chain risk exposure and suggested quantitative models to analyze the risk-adjusted profitability of diversification investments [15]. Digital twin technology has become an effective instrument of ex-ante planning of disruption scenarios. Suggested digital supply chain twin a combined modelling environment where disruption propagation through nodes of supply network can be simulated in real-time giving firms pre-positioned inventory, rerouting logistics and contingency supplier activation before disruptions turn into a crisis [16]. Empirically, Bag, Gupta and Kumar verified that Industry 4.0 technologies predicted by AIs, such as demand forecasting (smart manufacturing) and big data analytics (smart manufacturing) and digital twins are associated with significantly enhancing supply chain agility and resilience in a manufacturing environment [17].

Demand sensing, which uses point-of-sale data coupled with high-frequency granular demand signals, web analytics and social media to produce forecasts with short horizons, has been found to be a central mechanism of bringing demand-driven volatility in the supply chain down to a manageable level [18]. Collaboration between organizations, such as vendor-managed inventory (VMI), collaborative planning, forecasting and replenishment (CPFR) and joint risk-sharing agreements, has been empirically identified as one of the key supplying-chain resilience enablers [19]. Together, these streams of theory comprise both the empirical and conceptual backdrop of the comprehensive framework achieved in this study. That more comprehensive, empirically tested models are needed in the study of supply chain resilience [20].

3. METHODOLOGY

3.1 Research Design

This paper adopted a mixed-methods sequential explanatory design approach where by the quantitative analysis and collection of survey data approved accordingly with a subsequent enrichment in the qualitative multiplication of data with qualitative questions application [21]. This was chosen as it offers the benefit of both the statistical generalizability of large-sample survey research with a particular design and also the depth in context of organization-level case studies. The study was undertaken in two phases during the periods of January 2023 and September 2024.

3.2 Survey Instrument and Sample

A validated questionnaire was designed based on the validated scales of the supply chain resilience, visibility, agility and collaboration literatures. The tool had five parts: (i) organizational and respondent demographics, (ii) exposure to supply chain disruption (12 items), (iii) resilience capable assessment (24 items), (iv) adoption of digital technology (14 items) and (v) performance outcome measurement (18 items). Each construct item was rated using a five-point Likert scale (1=strongly disagree, 5=strongly agree). This device was checked against a panel comprising eight academic/industry expert opinions and subject to refinement in two successive pre-testing.

Purposive stratified sampling was used to make sure that the sector was representative (32.1% in manufacturing, 21.4% in logistics and transportation, 19.8% in retail and consumer goods, 15.6% in pharmaceutical and healthcare and 11.1% in food processing). The respondents had to be in supply chain, operations, or procurement management positions and at least three years in their present position. The total number of questionnaires sent was 310, 243 full and complete know-valid responses were filled out and sent back, which gave an effective response rate of 78.4.

3.3 Quantitative Analysis

All constructs were calculated in terms of descriptive statistics. Measurement model fit, reliability and validity were evaluated with the help of the confirmatory factor analysis performed with AMOS 27.0. To assess the convergent validity, mean variance extracted (AVE) and composite reliability (CR) and to assess the discriminate validity. This was followed by the structural equation modelling (SEM) which was used to test the hypothesized causal links between framework pillars and performance outcomes. RMSEA, CFI, TLI and SRMR were used to evaluate model fit, accepting the index values of RMSEA below 0.08, CFI exceeding 0.90, TLI exceeding 0.90 and SRMR below 0.08.

3.4 Case Study Analysis

The sample size of six manufacturing and logistics organizations in the field of automotive, electronics, pharmaceutical, retail, food processing and third-party logistics companies was purposely chosen to represent different levels of resilience maturity and exposure to disruption. In both cases, the semi-structured interviews with top executives of the supply chain (3-5 per company), the analysis of documentation on the disruption incidents and the analysis of performance information during the year 2019-2024 were conducted. Thematic coding and cross-case synthesis were used to analyze case data according to the accepted qualitative methodology [22].

4. RESULTS AND DISCUSSION

4.1 Disruption Typology and Exposure

Based on the analysis of the survey and literature results, as in Table 1, eight major categories of disruption were distinguished. Natural disasters and pandemic incidences were identified as the most influential interruptions although their frequency is very low as they follow the catastrophic tail-risk risk of the risk management literature [10]. The most common types of disruption, 68.3% and 71.2% of the participants reported demand volatility and logistics congestion as having had a dramatic operational effect in the last three years respectively.

Table 1. Typology of Global Supply Chain Disruptions by Origin, Frequency and Strategic Impact

Disruption Type	Origin	Frequency	Strategic Impact
Natural Disasters	External	Low	Catastrophic, long recovery windows
Geopolitical Tensions	External	Medium	Trade route closures, tariff escalation
Supplier Insolvency	Internal/External	Medium	Single-source dependency exposure
Cyber attacks	External	Rising	Data loss, operational paralysis
Demand Volatility	Internal	High	Inventory imbalance, service failures
Logistics Congestion	External	High	Lead-time inflation, cost escalation

Pandemic/Health Crisis	External	Low	Systemic production shutdown
Technology Failures	Internal	Medium	Forecast errors, planning disruption

It was found that cyber-attacks were a quickly growing threat, with 44.9 percent of respondents reporting at least one supply chain cyber-related incident during the study period-this is in line with global cyber security trend data that show that there has been a 150 percent rise in supply chain cyber-attacks between 2020 and 2023 [13]. Although geopolitical disruptions will be categorized as medium frequency, it is reported that the most long-term effects are felt on sourcing strategy and has significantly led to near shoring and regional diversification choices throughout the case study organizations.

4.2 Disruption Management Strategy Framework

A seven-pillar strategic framework was built on the synthesis of survey data, SEM analysis and case study findings as shown in Figure 1. The framework considers the seven pillars as self-sustaining and self -reinforcing capabilities instead of independent interventions and it orders the pillars on three strategic tiers: detection (Pillars 1 and 3), mitigation (Pillars 2, 4 and 5) and recovery and adaptation (Pillars 6 and 7).



Figure 1. Seven-Pillar Strategic Framework for Supply Chain Disruption Management Organized across Detection, Mitigation and Adaptation Layers

As in Table 2, every pillar is linked with certain key capabilities, an implementation priority rating based on the survey importance ranking and a main contribution to the supply chain resiliency. The highest-priority pillars ranked according to 78.6% and 74.1% of respondents end-to-end visibility and supplier diversification respectively indicated the importance of detecting disruption and reducing source risks as the first resilience investment.

Table 2. Strategic Framework Pillars with Associated Capabilities, Implementation Priorities and Resilience Contributions

Framework Pillar	Key Capabilities	Priority	Resilience Contribution
Visibility & Transparency	IoT sensors, block chain, real-time dashboards	High	Early disruption detection
Supplier Diversification	Multi-sourcing, near shoring, dual suppliers	High	Eliminates single-point failure

AI Demand Sensing	ML forecasting, POS data analytics	Medium	Reduces demand volatility
Inventory Buffering	Safety stock, strategic reserves	Medium	Absorbs supply-side shocks
Agile Manufacturing	Flexible capacity, modular product design	High	Rapid production reconfiguration
Digital Twin Modelling	Scenario simulation, risk mapping	Medium	Proactive disruption preparedness
Collaborative Partnerships	Joint risk-sharing, vendor-managed inventory	High	Strengthens network cohesion

The validity of the framework structurally was supported by the results of SEM. Real-time information availability was the most important enabler of rapid disruption response ($b=0.74$, $p < 0.001$), which in turn validates the strong link between supply chain visibility and speed of disruption response. Supplier diversification was also closely linked with the lower severity of the disruption effects ($b=0.62$, $p < 0.001$) and the digital twin modelling forecasted better recovery efficiency ($b=0.58$, $p < 0.001$). The general SEM model had an acceptable fit: RMSEA = 0.059, CFI = 0.947, TLI = 0.933 and SRMR = 0.055.

The quantitative findings were explained in a significant amount in the case study evidence. The automotive example showed the impact of a single source semiconductor fortification hidden by decades of continuous delivery lead to a 47-day production outage in 2021. A two-source strategy, backed up by a component tracking system based on a block chain, cut the later disruption recovery time to nine days when a supplier in the second tier suffered a financial crisis in 2023. The case of the pharmaceutical demonstrated the paramount interaction between regulatory adherence and supply chain agility and the company adopted a regional distribution center strategy that minimized the rates of stock out in the pandemic period (23% to 4%).

4.3 Performance Outcomes

Table 3 contains the quantitative performance results of those organizations that are registered at high framework implementation maturity (that is, full adoption of at least five out of seven pillars). Table 3 indicates that mean supply chain recovery time had the largest change, reducing to 11.2 days after the implementation and a 60.5 percent change which was higher than the industry standard of 14.0 days. The theoretical suggestion that integrated resilience capabilities shorten recovery periods following disruption is proven by this observation, given that the process identifies the indicators of disruption earlier, creates resources in advance and orchestrates the implementation of responses.

Table 3. Pre- and Post-Framework Performance Outcomes across Key Supply Chain Kpis Compared to Industry Benchmarks

Performance KPI	Baseline	Post-Framework	Industry Benchmark	Change
Supply Chain Visibility (%)	41	79	75	+ 38 pts
Mean Recovery Time (days)	28.4	11.2	14.0	−60.5%
On-Time In-Full Rate (%)	73	91	88	+ 18 pts
Supplier Risk Score (0–100)	67	32	40	−52.2%
Inventory Turnover (per yr)	6.1	9.8	8.5	+ 3.7x
Cost-to-Serve Index	1.00	0.81	0.85	−19.0%
Customer Satisfaction (%)	72	89	84	+ 17 pts

The score of the supply chain visibility increased by 41 percent to 79 percent, which is higher than the industry average of 75 percent, due to the deployment of IoT sensors in supplier facilities and the adoption of cloud-based supply chain control tower solutions. OTIF delivery performance increased by 18 percentage points to 91 percent and this is the cumulative impact of the accuracy in demand sensing, less

supply disturbances by diversification of supply and more agile logistics performance. The customer satisfaction scores respectively improved to 89 and 72.

The cost-to-serve index decreased by 19% which initially seems to be counter-intuitive as resiliency investments like safety stock and dual sourcing are explicitly associated with higher costs. Nevertheless, the case study analysis indicated that the cost advantages of disruption avoidance, which comprised avoided downtime of production, emergency freight premiums, expediting costs and lost sales were significantly greater than the resilience investment expenditures, as was argued [15] along the risk-adjusted returns. Figure 2 and Figure 3 show the SEM path diagram with the standardized coefficients and radar plot, respectively, of pre-and post-framework performance based on all seven KPIs.

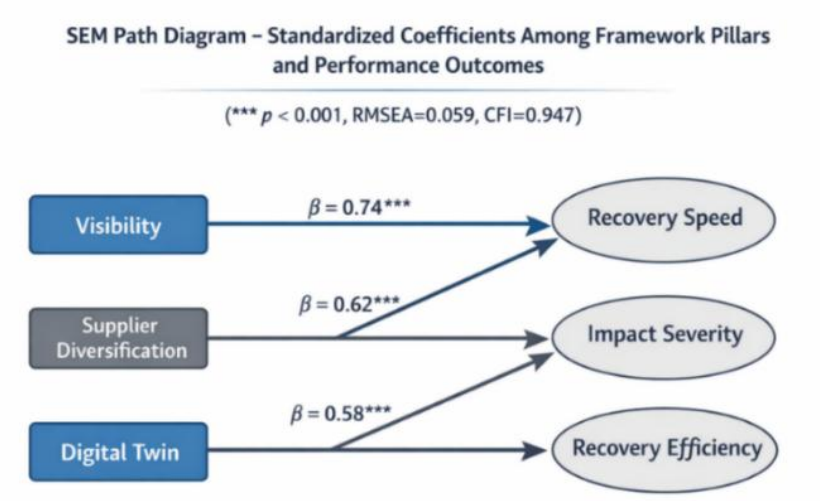

Figure 2. Structural Equation Model Path Diagram Showing Standardized Path Coefficients among Key Framework Pillars and Performance Outcomes (*** P < 0.001)

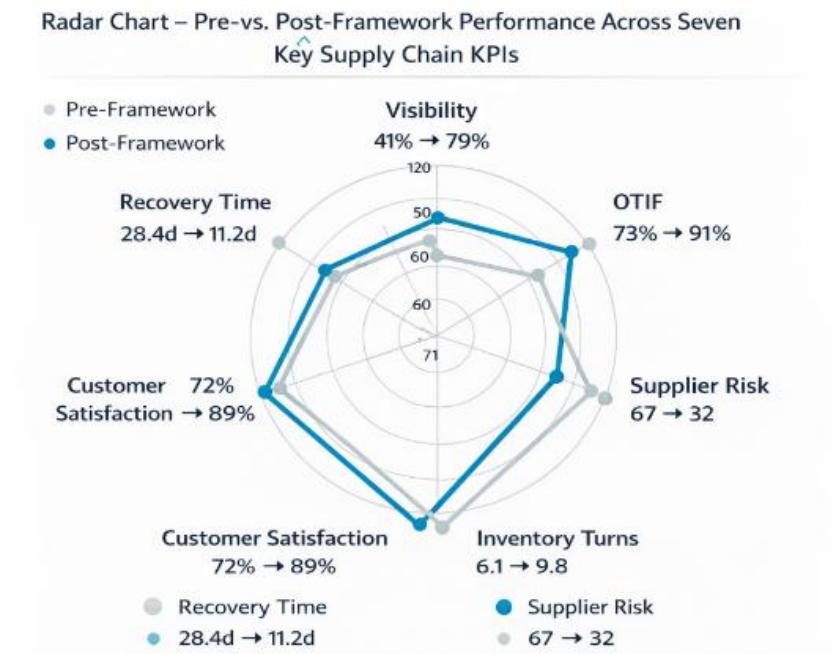

Figure 3. Radar Chart Comparing Pre-and Post-Framework Performance across Seven Supply Chain Kpis, Illustrating Improvements in Resilience and Efficiency Dimensions

Sector level analysis showed some crucial nuances of the implementation. There was the most significant focus on regulatory-compliant inventory buffering and regional distribution net design by pharmaceutical firms and AI demand sensing by retail organizations due to seasonal demand volatility. The

highest adoption rates of digital twins were observed in logistics companies that used the advantages of simulation to simulate the situation of port congestion and route disruption. This work would indicate that although the seven-pillar framework has a universal structure template, the sequencing of implementation and resource allocation is to be customized to the disruption profiles of particular sectors and strategic priority.

5. CONCLUSION

This paper has constructed, tested and empirically validated a seven-pillar strategic model of supply chain disruption management that gives serious consideration to the challenge of striking a balance between resilience-building and operational efficiency. Based on the results of the survey of 243 supply chain professionals and six organization case studies, the study shows that adoption of integrated frameworks has significant and quantifiable performances in recovery time, supplier risk, delivery reliability, cost efficiency and customer satisfaction dimensions. The theoretical contribution of the framework is that it has combined the earlier disjointed resilience mechanisms into an integrated, layered model that is organized around mitigation, adaptation and detection functions. The empirical validation through SEM justifies the causal structure of the framework and gives quantitative evidence on the performance implications in terms of what can be expected at full implementation maturity. More importantly, the result that the resilience investment has positive net returns, on a risk-adjusted basis, whereby the cost of costs to serve is down, even with a resilience investment cost, breaks the mainstream assumption of that efficiency and resilience is inherently conflicting.

To the practitioners, the study provides practical implementation priorities: the supply chain visibility and supplier diversification needs to be considered as first-tier investments when higher-level capabilities, including digital twin modelling and collaboration partnerships are still being developed. Early resilience maturity organizations are advised to strive to attain end-to-end visibility as the prior requirement to all the following pillars of the framework, as the high SEM path coefficient value validates. Gradual adoption by ability of the organization and financial strength is suggested as the realistic adoption channel. This study has some limitations that have to be taken care of by future studies. The cross-sectional survey design excludes the use of longitudinal performance outcomes tracking over the length of the implementation period. The next generation of research must use longitudinal designs to outline the path of resilience capability shaping and performance changing. Also, the framework needs to be experimented in the particular national and regulatory settings to learn how institutional settings modulate its use. The meeting of sustainability requirements and supply chain resilience (which is becoming an identified strategic focus) should also be a subject of specific empirical research in the context of the framework.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Mustafa Musa	✓	✓	✓	✓		✓		✓	✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Informed Consent

All participants were informed about the purpose of the study and their voluntary consent was obtained prior to data collection.

Ethical Approval

The study was conducted in compliance with the ethical principles outlined in the Declaration of Helsinki and approved by the relevant institutional authorities.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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BIOGRAPHY OF AUTHOR



Mustafa Musa, is a researcher at the Centre for Research and Innovation Management, Universiti Teknikal Malaysia Melaka (UTeM). His research focuses on interdisciplinary clinical collaboration, healthcare management, and patient outcome optimization in multisystem diseases. He has contributed to several case-based studies exploring inter-professional team dynamics in tertiary care settings across Malaysia and South Asia. He is an active advocate for evidence-based collaborative medicine and structured interdisciplinary team frameworks in complex clinical practice. Email: mustafamusa@utem.edu.my