TRANSNATIONAL ACADEMIC JOURNAL OF ECONOMICS

TACJE

Transnational Academic Journal of Economics, Year: 2025, Volume: 2, Issue: 2, Pages : 152-156 *Research Article*

DOI: 10.5281/zenodo.18442616

Publication Date: 30.05.2025

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Supply Chain Resilience Metrics: Optimization under Multi-Risk Shocks

Abstract

Background: Modern supply chains are exposed to multi-risk shocks that interact across demand, supply, logistics, finance, and cyber domains. These interactions challenge resilience scorecards that rely on isolated indicators. **Methods:** This review synthesizes definitions of supply chain resilience, operational resilience metrics, and robust and risk-averse optimization frameworks. We develop a measurement-to-decision pipeline that links stress scenarios to policy choices. **Results:** We identify a compact and operationally meaningful metric set—time-to-survive (TTS), time-to-recover (TTR), service continuity, and cost-to-serve—and show how these metrics can be embedded in robust, minimax, and CVaR-based optimization formulations. We describe how structured multi-risk stress scenarios translate metrics into decisions on inventory buffers, backup capacity, sourcing diversification, and logistics routing. **Conclusions:** Conclusions: Resilience metrics become operationally useful when tied to explicit decision levers and validated through structured stress tests, not treated as stand-alone scorecards.

Keywords: supply chain resilience; multi-risk shocks; resilience metrics; robust optimization; stress testing; service continuity; uncertainty sets; risk-averse optimization

How to cite: Begen M. A. Supply Chain Resilience Metrics: Optimization under Multi-Risk Shocks. *Transnational Academic Journal of Economics, 2*(2), 152-156

1. Introduction

Supply chain resilience is often defined as the capability to anticipate, absorb, adapt to, and recover from disruptions. In practice, resilience becomes actionable only when translated into measurable quantities linked to controllable decisions such as safety stock, backup capacity, supplier diversification, and logistics routing.Multi-risk shocks complicate both measurement and decision making. A demand surge may coincide with supplier downtime; a port disruption can amplify working-capital pressure; and a cyber incident can reduce visibility precisely when flexibility is needed. Because risks interact, managers need interpretable metrics under joint stress and optimization models that can select policies under uncertainty.

2. Materials and Methods

This manuscript follows a structured narrative review. First, we consolidate commonly used resilience definitions and translate them into measurable constructs. Second, we organize metrics into four families: (i) survival and recovery times, (ii) service continuity, (iii) cost and financial strain, and (iv) variability/volatility indicators. Third, we discuss how these metrics appear in optimization models, including minimax robust optimization and risk-averse variants such as CVaR.In line with robust optimization, uncertainty is represented through sets (e.g., demand bands, lead-time bounds, capacity loss ranges). Policies are assessed by worst-case or stress-case performance within these sets, supporting governance-oriented decision making.

3. Results

3.1 Metric families. Time-to-survive (TTS) and time-to-recover (TTR) provide an operational lens: TTS approximates how long the supply chain can keep meeting demand under disruption, while TTR captures the recovery time to a stable service level. Service continuity metrics (fill rate, OTIF) capture customer-facing performance, while cost-to-serve aggregates expedited freight, overtime, scrap, and financing costs.
3.2 Embedding metrics in optimization. Robust optimization seeks decisions that remain feasible across realizations in an uncertainty set. Risk-averse formulations balance tail losses against average performance, enabling explicit governance thresholds.
3.3 Stress testing protocol. A practical approach defines a finite library of multi-risk scenarios (e.g., demand surge plus supplier downtime plus port delay), computes metrics for each scenario, and selects policies that minimize regret or constrain maximum loss across scenarios.

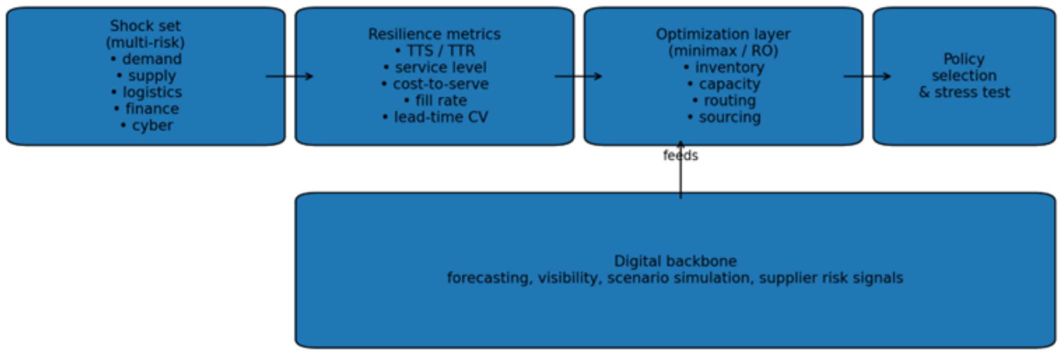
4. Discussion

Resilience scorecards often fail when they ignore decision context. A metric that cannot be influenced by a policy lever is not a management tool. The highest-value metrics are those that change meaningfully under realistic policies, map to service promises, and support transparent trade-offs between redundancy and efficiency.Overreliance on a single metric is risky. A policy that minimizes recovery time may inflate cost-to-serve beyond what the business can finance. Multi-objective modeling and explicit governance thresholds help avoid false optimization.Future research should compare metric sets across industries and examine how early warning signals (supplier financial health, cyber alerts) should update uncertainty sets in real time.

5. Conclusions

Resilience measurement is not a reporting exercise; it is a decision system. The strongest operational designs use a small set of interpretable metrics and combine them with robust and stress-tested optimization to select policies under multi-risk uncertainty.

Figure 1 (Conceptual)



Measurement-to-optimization pipeline for resilience decisions under multi-risk shocks

Table 1

Practical supply chain resilience metrics and how they link to decisions.

Metric	Interpretation	Example decision lever	Typical data needed
Time-to-survive (TTS)	Duration service can be maintained under disruption	Safety stock; alternate supply	Inventory, demand, disruption duration
Time-to-recover (TTR)	Time needed to restore target performance	Backup capacity; expedited modes	Capacity, lead times, recovery constraints
Fill rate / OTIF	Customer service continuity	Allocation rules; prioritization	Orders, shipments, promise dates
Cost-to-serve	Cost to deliver service under stress	Mode selection; overtime policy	Freight, labor, working capital
Lead-time variability	Volatility in replenishment	Supplier diversification; buffers	Lead-time history, transit events

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