Optimal Risk-Mitigation Investments in

Tempur-Pedic's Mattress Supply Chain Network

by

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ABSTRACT

Tempur Sealy International faces a complex supply chain investment challenge: how to allocate risk-mitigation resources across inventory, sourcing, production, and logistics while preserving high customer service levels for its premium Tempur-Pedic mattress portfolio. This study investigates how different types of disruptions can cause service-level declines and how the company should prioritize risk-mitigation investments across its end-to-end network. To address this problem, we developed a multi-period Mixed-Integer Linear Programming model of the logistics network in the U.S., tested it under plant shutdown and supplier disruption scenarios, and complemented it with targeted trade-off analyses of alternative inventory strategies to assess their impacts on financial metrics. The results indicate that finished goods inventory serves as the most effective and broadly applicable lever for maintaining service levels across both production-side and supplier-side disruptions. A 20% increase in finished goods inventory is 1.4 times more effective at mitigating lost sales than an equivalent increase in raw materials inventory. Additionally, the analysis suggests that plant outages can often be mitigated through network flexibility, rather than immediate service-level reduction. Based on these findings, we propose a prioritized set of five risk-mitigation investments: (1) increasing or at least maintaining current finished goods inventory, (2) implementing added buffers for critical raw materials, (3) enhancing outbound logistics flexibility across distribution centers, (4) improving inbound logistics flexibility for raw material flows, and (5) expanding production flexibility to enable all plants to manufacture the full product portfolio strategically. Collectively, these recommendations provide a structured roadmap for strengthening supply chain resilience by making the most effective investments.

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1. Introduction

The sponsor company, Tempur Sealy International (TSI), a subsidiary of Somni Group International, is a marketer and producer of mattresses and bedding products in the United States with four brands: Tempur-Pedic, Sealy, Stearns and Foster, and Sherwood Bedding. The sponsor company is headquartered in Kentucky, USA, with a global employee base of approximately 13,000 people, and it generated US $4.9 billion in net sales in 2024 (TSI, 2025). TSI operates many production facilities and distribution centers across the United States, strategically positioned to deliver high service levels to customers throughout North America. TSI also maintains a broad international presence, with 38 factories worldwide and over 750 company-owned retail stores (TSI, 2025). This extensive global network enables TSI to manufacture and distribute its products at scale, through e-commerce, retail stores, and Business-to-Business (B2B) platforms.

1.1 Motivation

TSI has maintained strong cash flows and is well-positioned to make targeted investments that protect revenue, sustain service levels, and safeguard profitability. However, determining where to allocate these investments presents a complex challenge. The company's leadership therefore seeks a systematic, data-driven approach to evaluate investment options and identify the most effective investment strategies for strengthening its supply chain performance.

Among the top opportunities are two interconnected priorities: enhancing supply chain resilience and reducing supply chain risk. Potential triggers of risks include production and packaging material shortages, plant or distribution center shutdowns, capacity constraints, inventory imbalances, and logistics delays. Currently, TSI implements risk-mitigation strategies within various functions of its supply chain. Examples of levers that can be deployed include increasing raw material (RM) inventory, expanding finished goods (FG) days-on-hand, investing in additional production capacity, or improving logistical flexibility.

However, these investments in risk mitigation and supply chain resilience are not coordinated across departments and facilities and are executed independently. This fragmented approach leads to redundancies, potentially inefficient investments, and sub-optimal performance when the entire supply chain is considered. Moreover, each strategy carries different cost implications and operational trade-offs.

Understanding the existing risk-mitigation strategies and their impact on service levels and revenue at each supply chain node and function will enable the sponsor company to evaluate the effectiveness of its existing efforts across its supply chain. This approach will also highlight opportunities to eliminate unnecessary buffers, identify areas where additional resources could enhance performance, and fully leverage its investments with an end-to-end, cross-functional perspective. Ultimately, TSI aims to improve visibility and integration of risk-mitigation investments to strengthen its overall organizational resiliency.

As a proof of concept, the sponsor company will explore supply chain risks associated with one of its premium product lines, Tempur-Pedic mattresses. As a market leader in innovation with no close substitutes, the Tempur-Pedic brand represents a major strategic asset for the company. With retail prices reaching up to approximately USD $10,000 per mattress, depending on the model, these products serve as key profit drivers and generate substantial margins for the organization (TSI, 2025). Given the high value of these products and their importance to the company's financial performance, TSI seeks to proactively ensure that it can consistently meet customer demand across the entire Tempur-Pedic portfolio. To support this objective, the company wants to determine the optimal allocation of risk-mitigation investments, taking into account the cost, service, and operational trade-offs involved.

1.2 Problem Statement and Key Questions

To determine the optimal allocation of risk-mitigation investments across TSI's network, we examined trade-offs among RM inventory, FG inventory, production capacity, and service levels at both manufacturing and distribution facilities while accounting for cost and revenue impacts. The scope of this methodology spans sourcing RMs through the delivery of FGs to distribution centers.

The key questions to address are:

- What are the principal supply chain failure modes that can lead to lost sales in the Tempur-Pedic network, and how do these differ between plant-side disruptions and upstream material disruptions?
- How do alternative resilience levers, including FG inventory, RM inventory, and logistics or network flexibility, affect service performance under different disruption scenarios?
- How should Tempur Sealy allocate risk-mitigation investments across the supply chain to reduce revenue exposure and preserve customer service most effectively?
- How can upstream and downstream mitigation strategies be integrated into a coordinated end-to-end resilience approach?

To quantitatively evaluate the above-mentioned trade-offs, we developed a Mixed-Integer Linear Programming (MILP) optimization model that compares alternative inventory positioning strategies—specifically, the allocation of RM inventory at production sites versus FG inventory at distribution centers. The model was tested under a range of disruption scenarios to assess system resilience and performance sensitivity.

1.3 Project Goals and Expected Outcomes

The project develops a prioritized roadmap to guide the sponsor company's future risk-mitigation investments. To achieve this, the proposed methodology evaluates the potential service-level impacts of various risk triggers across the company's supply chain. Rather than an implementation plan, the project is designed as a decision-support tool that enables a more holistic approach to risk mitigation. The success of the project will depend on the adoption of this tool and the ability to dynamically update key parameters as new data becomes available. Deliverables to the sponsor company include:

- A methodology that quantifies the impact of various risks across the Tempur-Pedic mattress's E2E supply chain while optimizing the risk-mitigation efforts over its upstream and downstream nodes.
- A dynamic model that outlines the potential service loss due to risk triggers in the E2E supply chain by analyzing capacities, inventories, and costs.

Implementing this approach will provide TSI and similar organizations with a clearer understanding of the trade-offs among different supply chain investment options. By systematically evaluating operational levers such as FG inventory, RM inventory, production capacity, and logistics flexibility, the methodology enables companies to strategically quantify the cost and service-level implications associated with each alternative. For example, the model enables estimating service-level impacts under alternative inventory configurations, such as increasing the FG inventory by 20% while maintaining the same RM inventory. Because these two strategies, holding inventory upstream in the form of RM versus downstream as FG, entail distinct cost structures and operational implications, the analysis facilitates a transparent comparison of the associated financial and service tradeoffs. This, in turn, supports more informed decision-making regarding optimal inventory positioning within the network. Beyond the sponsor company, this framework can be applied by other manufacturing organizations facing similar challenges in balancing supply chain resilience, service levels, and inventory investment decisions.

2. State of the Practice

Our capstone explores how our sponsor company can allocate its risk-mitigation investments most effectively while maintaining target service levels. To address the questions in scope, we reviewed several sources in the literature across relevant fields. First, we examined the current common practices for mitigating supply chain risks. Second, we reviewed the quantitative approaches for measuring revenue-at-risk. Lastly, we assessed network design optimization methods.

2.1 Current Common Practices for Supply Chain Risk Mitigation

Companies around the world face many different supply chain risks every day. Liagkouras and Metaxiotis (2023) conducted a comprehensive review of supply chain uncertainties, identifying 13 major risk categories ranging from demand uncertainties to environmental risks. One category is disruption risk; it is most relevant to our sponsor company, as many of its chemical suppliers are located near the U.S. Gulf Coast. The Gulf Coast is prone to disruptions triggered by hurricanes. The authors stated that diversifying suppliers is an essential buffer to mitigate natural-disaster-related disruptions (Liagkouras and Metaxiotis, 2023). To illustrate this, back in 2000, a fire erupted at a plant in New Mexico. This plant was a supplier for Ericsson; unfortunately, since Ericsson didn't diversify and relied solely on this supplier, the plant shutdown resulted in a US $400 million revenue loss (Minner and Silbermayr, 2023). Echoing the concept of supplier diversification, many companies have adopted dual sourcing. According to Rice (2006), building relationships with only one supplier limits flexibility in times of crisis, so creating a diverse base is critical.

Aside from procurement, inventory management is also an important supply chain asset during periods of disruption. Research by Bode and Wagner (2015) demonstrates that stockout disruptions occur frequently in complex supply chains. As complexity within a firm increases, inventory buffers need to be created across other logistics nodes to prepare for sudden disruptions. Further evidence by Dzreke and Dzreke (2025) shows that lean corporations (defined by inventory-to-sales ratio) experience 3.2 times greater revenue losses than their peers when geopolitical disruptions occur. Together, these findings highlight the importance of keeping strategic inventory buffers to protect firm performance during periods of uncertainty.

Additionally, forecasting is a critical component of supply chain management that directly influences both top-line revenue growth and bottom-line profitability (Ying, 2023). Accurate demand forecasting enables organizations to better align production plans with market demand, thereby reducing the likelihood of stockouts and lost sales. At the same time, improved forecast accuracy helps to minimize excess inventory, which in turn lowers inventory carrying costs and reduces rush-shipment logistics costs. The author further quantifies the financial impact of forecasting, estimating that for every 10-20% increase in forecast accuracy, firms may experience a corresponding 2-3% increase in revenue.

Lastly, these methods provide a solid foundation for mitigating risks during disruptions, but they are siloed, applying only to selected segments of the broader supply chain network. As we consider the complex supply chains of global companies, a holistic mapping approach will be more comprehensive to address all layers of this dynamic system. According to Simchi-Levi and Simchi-Levi (2020):

> The best way to make supply chains more resilient is by mapping the layers of suppliers, manufacturing plants, distributors, and other elements of the logistics network and applying a stress test to evaluate the ability to recover from the disruption of these sites. Once there is an understanding of where bottlenecks are located, various mitigation strategies can be considered, including adding manufacturing capabilities or suppliers or creating buffer stocks (D. Simchi-Levi and E. Simchi-Levi, 2020).

2.2 Methods for Quantifying the Impact of Supply Chain Risks

Most corporations understand that natural disaster-related disruptions need to be considered when designing the supply chain; however, they are often unsure how to measure the financial damage to their company in the aftermath. The financial impact of disruptions is typically represented by shortage costs, lost sales, and goodwill losses (Kumar, 2010). In addition, Chopra and Sodhi (2004) identified revenue loss as one of the most damaging consequences of supply chain breakdowns, arguing that firms often underestimate its strategic significance.

The Time-to-Survive/Time-to-Recover (TTS/TTR) framework developed by Simchi-Levi (2015) has become a widely adopted method for quantifying resilience and linking disruptions to revenue loss. Time-to-Survive (TTS) measures how long a supply chain can continue meeting demand after a node fails, based on existing inventory, alternative capacity, and network flexibility. Time-to-Recover (TTR) measures how long it takes the disrupted node to return to full operational output.

Disruption leads to lost sales only when recovery takes longer than the system can survive, meaning TTR is greater than TTS. The length of this gap represents the period during which customer demand cannot be fulfilled. Firms convert this service gap into revenue loss by multiplying the duration of unmet demand by the expected daily sales (or profit contribution) of the affected products. In this way, the TTS/TTR framework provides a straightforward method for translating operational vulnerability into financial impact, enabling companies to identify the nodes where insufficient buffering or long recovery times create the greatest revenue risk.

Another framework used to quantify the impact of disruptions is the Expected Total Opportunity Cost (E(TOC)), introduced by Bandaly et al. (2016), which measures revenue exposure arising from lead-time variability. In this approach, service loss is evaluated by estimating the demand that cannot be fulfilled when actual lead times deviate from planned values. Even small increases in lead-time variability raise the probability that replenishment will arrive late, reducing available inventory at the moment of demand and leading to lost sales. These lost sales are then multiplied by their contribution margin to estimate the total opportunity cost.

In research conducted by Braud and Gong (2016), their sponsor company deployed a method that measured the company's Risk Exposure Index by multiplying the Revenue at Risk by expressing the difference of (Time-to-Recover – Inventory Days of Supply). This quantitative reference is then complemented by qualitative interviews with the firm's supply chain leaders. This hybrid method, which combines quantitative formulas with qualitative inputs, provides one of the strongest frameworks for quantifying supply chain risks.

Lastly, Siu and Stephen (2015) quantified Expected Business Impact, as seen in Figure 1. This approach added a layer of probability, weighting the impact by the likelihood of occurrence. Given that some disruptions will occur more frequently than others, this approach prioritizes high-probability events for a concentrated focus.

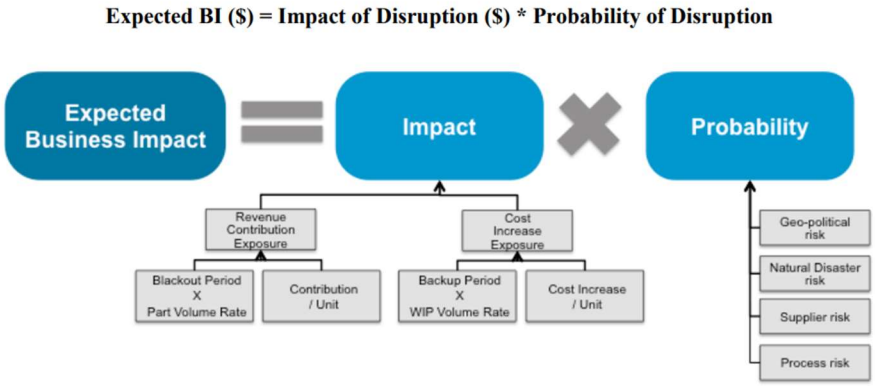


Figure 1. Formula for Calculating Expected Business Impact (Siu and Stephen, 2015)

2.3 Network Design Optimization

Network design optimization is among the most advanced analytical approaches for improving supply chain resilience. While risk frameworks such as TTS/TTR or E(TOC) quantify a disruption's operational and financial effects, network design research focuses on structuring the supply chain, including elements such as its sourcing footprint, capacity allocation, inventory placement, and production flows, to withstand uncertainty and maintain service levels.

A central tool in this domain is the MILP model, which combines linear cost and flow relationships with integer decisions (e.g., opening a facility, selecting suppliers, activating backup capacity) to identify the best-performing network configuration under given constraints. It can simultaneously incorporate:

- multi-echelon flows (supplier → manufacturing plant → distribution center → customer)
- capacity and throughput limitations
- sourcing and allocation choices
- inventory and safety stock decisions
- disruptions modeled as changes in capacity, cost, or lead time

MILPs provide a rigorous framework for evaluating trade-offs among cost, service level, and risk exposure, making them well-suited to support strategic resilience decisions.

Academic literature consistently demonstrates that networks designed using uncertainty-aware MILP frameworks perform markedly better than deterministic designs. Kumar (2010) showed that embedding demand variability, lead-time risk, production reliability, and exchange-rate fluctuations into the optimization process results in sourcing and flow decisions that explicitly account for uncertainty and operational risk, in contrast to deterministic models that prioritize cost minimization without considering real-world variability. Santoso (2005) developed a two-stage stochastic MILP in which the first stage determines that strategic decisions (i.e., facilities, capacities) are robust across scenarios, while the second stage manages operational decisions to adapt to realized disruptions—yielding lower cost variability and stronger resilience.

A key insight from more recent work is that risk quantification alone, such as ranking nodes by Value-at-Risk (VaR), is insufficient for determining how to redesign or fortify the supply chain. Braud and Gong (2016) highlighted that firms can map vulnerability but cannot determine which risk-mitigation actions create the greatest value without linking those assessments to prescriptive optimization. Their work also demonstrates that node-level risks often stem from correlated disruption triggers, such as a supplier failure coinciding with extended transportation time, reinforcing the need for scenario-based network models.

Across the literature, network design under uncertainty seeks to answer four strategic questions:

1. Where should capacity be located?
2. How much flexibility should be built into the network?
3. What inventory levels are required to absorb disruptions?
4. How should sourcing be allocated across suppliers to minimize risk exposure?

The literature also reveals gaps that motivate more integrated approaches. Many models optimize cost but do not quantify revenue-at-risk, even though it is essential for executive decision-making (Kumar, 2010). VaR-based models identify vulnerabilities but do not prescribe mitigation actions (Braud and Gong, 2016). While the TTS/TTR framework is widely accepted (Simchi-Levi, 2015), few optimization models incorporate TTR-driven capacity loss as a constraint on feasible flows. Moreover, traditional industry tools often minimize costs or inventory without accounting for probabilistic, multi-node, or correlated disruptions.

These gaps underscore the need for network design models that directly integrate risk probabilities, recovery times, and financial exposure into MILP formulations, enabling firms to evaluate where and how much to invest in resilience. Consequently, network optimization provides the quantitative foundation for designing supply chain strategies that are not only cost-effective but also robust against real-world disruption scenarios.

Our research provides a strong foundation for our methodology. Key insights are summarized below:

1. Companies face diverse supply chain risks, including disruptions such as hurricane-related supplier shutdowns, underscoring the importance of supplier diversification, inventory buffers, and accurate forecasting to reduce revenue losses and improve resilience.
2. These strategies are often applied in isolation; thus, a holistic supply chain mapping and stress-testing approach is recommended to identify bottlenecks and implement comprehensive mitigation strategies across the entire network.
3. Frameworks such as TTS/TTR, Expected Total Opportunity Cost, Risk Exposure Index, and Expected Business Impact quantify operational disruptions as financial risk by linking recovery time and probability of occurrence to measurable revenue impact.
4. Existing MILP models can only quantify an isolated portion of the vulnerability; however, our improved model aims to evaluate a range of disruption scenarios to enable data-driven decision-making processes on where and how much to invest within and across the TSI supply chain.

3. Methodology

In this section, we deep-dive into the methodology selected to address our project's core objective. This includes our rationale for the chosen approaches, data required to support the analysis, and the step-by-step process of quantifying risk exposure and identifying the most impactful risk-mitigation investments.

3.1 Methodology Selection

Disruptions can be mitigated through three key levers: inventory buffers, capacity flexibility, and network redundancy (Rice, 2006; Bode and Wagner, 2015). However, these levers interact in complex ways across the supply chain, leading to inefficiencies due to their siloed nature. Following discussions with the sponsor company and a review of relevant resilience optimization literature, we adopted a two-step quantitative methodology anchored in MILP and complemented by scenario-based instances. The MILP model enables a comprehensive representation of the current supply chain network, allowing us to establish a baseline by estimating existing operating costs and system performance under steady-state conditions. Building on this baseline model, we then incorporate a range of realistic disruption scenarios to assess their impact on service levels and overall network performance. This approach allows us to systematically evaluate the

effectiveness of potential risk-mitigation investments and identify those that yield the greatest improvements in supply chain resilience.

3.2 Data Collection and Preparation

Data for relevant products have been collected from the sponsor company as follows:

1. Demand and Revenue Data: historical demand (weekly, by SKU), revenue (by SKU), RM Bill of Materials (BOM), and consumption rates
2. Inventory Data: internal inventory positions at plants (raw materials) and DCs (finished goods), external inventory positions (raw materials at supplier locations), pipeline inventory positions (raw materials en route to plants), target safety stock for raw materials and finished goods, average lead times and lead time variability
3. Capacity Data: production capacity by plant, and DC storage capacity
4. Production Data: production, handling, and inventory costs
5. Logistics Data: transportation rates (road, and interfacility in $/mile or $/ton), historical split between contracted rates and spot rates
6. Risk and Disruption Data: historical supplier delays (with root cause and Time-to-Recover), historical raw material quality issues, historical plant/DC outages, and downtime

Data preparation involved several steps to convert the sponsor company's Excel files into structured input files suitable for analysis in Python. First, a mapping table was created to standardize facility node names by converting them into shorter identifiers. For example, "Atlanta Distribution Center" was mapped to "DC1" to simplify subsequent data processing and modeling. Second, pivot tables were developed in Excel to standardize the time horizon across the dataset to a consistent 52-week period. This step ensured that data such as weekly RM usage were aligned with the annual demand forecasts. In addition, RM storage capacity was aggregated across all relevant locations, including railyards, external storage facilities, supplier storage, and in-house tanks. Finally, the processed datasets were consolidated into a single Excel file, which served as the primary input to the Python-based model.

3.3 Application of Methodology

To ensure a disciplined and routine approach to building, validating, and applying the MILP model, we follow a three-step analytical workflow that combines MILP optimization and scenario-based disruption instances:

Step 1: MILP Model Construction for Baseline

We first formulate a Mixed-Integer Linear Programming (MILP) model representing the end-to-end network across suppliers, US production plants, and DCs under normal operating conditions. We then quantify the baseline revenue-at-risk by identifying bottlenecks, capacity constraints, and service failures that might occur under current mitigation strategies and investments.

Key elements of the model include:

Sets:

$p \in P$: Set of plants

$d \in D$: Set of DC storage nodes

$d' \in D$: Set of DC demand nodes (each paired to a d)

$s \in S$: Set of suppliers

$r \in R$: Set of RMs

$k \in K$: Set of FG SKUs

$t \in T$: Set of planning periods (weeks)

Parameters:

$c^{log}_{p,d}$: Unit logistics cost from plant p to DC storage d (route-based; contract or spot rate)

$c^{rm}_{s,r}$: Unit RM cost from supplier s for material r

c^{prod}: Production cost per unit (uniform across all plants p and SKUs k)

c^{hold}: FG holding cost (applied to DC storage d and plants p) and RM holding cost (applied to plants p)

c^{trans}: FG transfer cost from DC storage d to DC demand d'

Decision Variables:

$Y_{p,d,k,t}$: Outbound flow, represents the quantity of FG k shipped from plant p to DC storage node d in week t

$X_{s,p,r,t}$: Sourcing quantity, represents the quantity of RM r sourced from supplier s by plant p in week t

$Q_{p,k,t}$: Production quantity, represents the quantity of FG k produced by plant p in week t

$I^{fg}_{d,k,t}$: FG inventory at DC storage, represents the inventory level of FG k at DC storage node d at the end of week t

$I^{fg}_{p,k,t}$: FG inventory at plant (pre-shipment), represents the inventory level of FG k at plant p at the end of week t

$I^{rm}_{p,r,t}$: Extra RM supply, represents the quantity of RM r acquired by plant p through emergency/spot purchases in week t

$Z_{d,d',k,t}$: FG transfer, represents the quantity of FG k transferred from DC storage node d to DC demand node d' in week t

Objective Function:

The objective is to minimize the total cost in multiple dimensions across a time horizon of 52 weeks, given by the formula:

$$\min \text{Total Cost}$$

$$\underbrace{\sum_{p,d,k,t} c^{log}_{p,d}\, Y_{p,d,k,t}}_{\text{1 Logistics}} + \underbrace{\sum_{s,p,r,t} c^{rm}_{s,r}\, X_{s,p,r,t}}_{\text{2 Procurement}} + \underbrace{\sum_{p,k,t} c^{prod}\, Q_{p,k,t}}_{\text{3 Production}} + \underbrace{\sum_{d,k,t} c^{hold}\, I^{fg}_{d,k,t}}_{\text{4 FG Holding (DC)}}$$

$$+ \underbrace{\sum_{p,k,t} c^{hold}\, I^{fg}_{p,k,t}}_{\text{5 FG Holding (Plant)}} + \underbrace{\sum_{p,r,t} c^{hold}\, I^{rm}_{p,r,t}}_{\text{6 Raw Material Holding (Plant)}} + \underbrace{\sum_{d,d',k,t} c^{trans}\, Z_{d,d',k,t}}_{\text{7 FG Transfer (DC → Demand)}}$$

Constraints

1. Supplier Annual Capacity:
    - For each supplier s and RM r, the total quantity of r procured by all plants over all weeks t cannot exceed the supplier's annual capacity, with a 10% buffer.
2. Plant Production Capacity:

- For each plant *p* and week *t*, the total quantity of all FG *k* produced cannot exceed the plant's production capacity.

3. FG Inventory Balance at Plants:
   - For each plant *p*, FG *k*, and week *t*, the inventory level at the end of the week equals the previous week's inventory *plus* production *minus* outbound shipments to DC storage.
   - For the first period, *t*=1, the previous inventory is 0.
4. RM Inventory Balance at Plants:
   - For each plant *p*, RM *r*, and week *t*, the inventory level at the end of the week *equals* the previous week's inventory *plus* supplier arrivals (including lead time) *plus* any additional emergency supply, *minus* consumption by production.
5. Maximum RM Inventory Capacity at Plants:
   - For each plant *p*, RM *r*, and week *t*, the RM inventory cannot exceed its maximum capacity.
6. FG Inventory Balance at DC Storage:
   - For each DC storage node *d*, FG *k*, and week *t*, the inventory level is *equal to* the previous week's inventory *plus* inflow from plants *minus* outflow to the corresponding DC demand node.
   - For the first period, *t*=1, the initial inventory is the sum of the first 6 weeks of demand for that *k* at that *d*.
7. Maximum FG Storage Capacity at DC Storage:
   - For each DC storage node *d*, FG *k*, and week *t*, the FG inventory cannot exceed the DC's maximum storage capacity.
8. FG Safety Stock at DC Storage:
   - For each DC storage node *d*, FG *k*, and week *t*, the FG inventory must be at least 6 weeks of forward demand.
9. Strict Demand Satisfaction at DC Demand (Same DC Supply Only):
   - For each DC demand node *d'*, FG *k*, and week *t*, the inflow from its corresponding DC storage node must be *greater or equal to* the demand for that *k* in that week.
10. No Future Emergency RM Purchases:
    - For each plant *p*, RM *r*, and week *t*, the quantity of extra RM supply is fixed at 0.

All decision variables are continuous and non-negative. The outcome of this model establishes the baseline operating costs under steady-state conditions.

Step 2: Scenario-Based Disruption Instances

In this step, we introduce realistic disruption scenarios to stress-test the supply chain model. These instances include multi-week plant shutdowns and temporary cutoff of key suppliers from the network, simulated at varying magnitudes to reflect different levels of impact. The multi-period MILP is then re-run for each disruption case to quantify the resulting service-level degradation caused by unmet demand.

Step 3: Prioritizing Mitigation Investments Based on Trade-off Analysis

The final step of the analysis translates scenario-based results into actionable investment recommendations. The primary objective is to identify which risk-mitigation interventions yield the greatest improvement in overall supply chain resilience. Inventory-related interventions are evaluated across varying levels of reduction to assess the trade-offs between incremental operating costs and potential lost sales. Interventions are subsequently prioritized based on their effectiveness in preventing service failures under disruption scenarios. This structured evaluation results in a ranked investment roadmap that aligns with TSI's resilience objectives.

3.4 Assumptions and Estimates Used in the MILP model

To make the model mathematically feasible, we made some generalizations and estimates. These were co-developed with the sponsor company based on best estimates using past data:

1. Cost Parameters
    a. Production Cost per Unit: Standardized estimate calibrated with sponsor inputs
    b. Finished Goods Holding Cost: Standardized estimate calibrated with sponsor inputs
    c. RM Holding Cost: $0.15 per unit per week
    d. Inter-DC Transfer Penalty Cost: $50.00 per unit
    e. Spot Market Logistics Cost: $0.05 per unit-mile
    f. Emergency RM Cost: $50.00 per unit for purchases made beyond the lead time
2. Capacity and Inventory Parameters
    a. Supplier Annual Capacity Buffer: 1.10 (a 10% buffer) applied to supplier annual capacities
    b. Manually Adjusted Raw Material Inventory: A critical RM at a particular plant is set to 2,000,000 units
    c. Initial Finished Goods Inventory at DCs: Set to the normalized demand distribution with 68% at six weeks, 13.5% at four-and-a-half weeks, 13.5% at seven-and-a-half weeks, 2.5% at three weeks, and 2.5% at nine weeks
    d. FG Safety Stock at DC Storage: Constrained to be at least the normalized demand distribution
3. Lead Times
    a. General RM Procurement Lead Time: 4 weeks
    b. Special RM Lead Time: 2 weeks
    c. Spot Market Transit Time: 0 weeks (same week delivery)

4. Results and Discussion

Building on the analytical workflow described in Section 3.3, this section presents the results of the baseline optimization, disruption scenarios, and trade-off analyses. We first report findings from the Base Model, which reflects the current operating state of the network, including emergency raw material procurement behavior. We then introduce the Modified Base Model, in which historical emergency procurement is embedded in the initial inventory and subsequent emergency purchases are disabled, so that subsequent scenario results reflect structural resilience levers rather than reactive rescue actions. Based on discussions with the sponsor and the project objective of comparing mitigation priorities across the E2E network, three disruption scenarios were selected to represent the most relevant failure modes: i) a plant shutdown to test manufacturing and distribution flexibility, ii) a multi-sourced RM disruption to assess the resilience of sourcing redundancy, and iii) a single-sourced raw material disruption to evaluate the network's exposure to concentrated upstream material risk. Finally, we use the single-sourced disruption case to conduct trade-off analyses comparing RM and FG buffers, since this scenario provides the clearest view of how alternative inventory strategies affect service levels, lost sales, and overall network response.

4.1 Base Model

The Base Model was designed to represent TSI's current operating state by allowing the network to use reactive measures when planned sourcing and production are insufficient to meet material requirements. In particular, the model includes an emergency RM procurement decision variable at the plant level to address shortfalls in inbound raw material availability and preserve feasibility.

The Base Model is solved as a deterministic multi-period MILP over a weekly planning horizon using Gurobi. The objective minimizes total system cost, including procurement, production, transportation, FG holding, and emergency RM procurement costs.

4.1.1. Results

The Base Model estimates total system costs over the planning horizon, with exact figures withheld for confidentiality. Material-related costs, including both contracted procurement and emergency RM purchases, account for the largest share, roughly 61% of total costs. Production costs account for approximately 25%, while outbound logistics, RM holding, and FG inventory holding drive the remaining costs. Emergency RM purchases are concentrated primarily in the first four weeks of the horizon.

This cost structure indicates that RM availability and procurement mode are the primary economic drivers of the modeled network. It also shows that early-horizon feasibility is supported in part by emergency procurement rather than entirely by planned sourcing and existing inventory buffers.

4.1.2. Implications

From a resilience perspective, the Base Model reveals two key insights. First, service performance is not driven solely by network design. Instead, it is enhanced by a reactive mechanism, emergency RM procurement. This secondary lever helps compensate for upstream fragility, such as single-sourced materials, long lead times, and gaps arising from initial model assumptions. When this option is available in disruption scenarios, the model can restore feasibility through emergency purchases. As a result, it may understate the true severity of structural vulnerabilities and underestimate revenue-at-risk.

Second, these findings indicate that planned resilience should be evaluated separately from reactive responses. Because the goal of this project is to recommend where TSI should invest in long-term, structural resilience, the analysis should focus on factors such as inventory positioning, production flexibility, and network design, rather than relying on emergency procurement. This need for a more accurate baseline directly motivates the Modified Base Model introduced in the next subsection.

4.2 Modified Base Model

The Modified Base Model is constructed by converting emergency RM procurement from an ongoing recourse mechanism into a one-time adjustment to the initial state of the system. Specifically, the aggregate emergency RM purchases observed in the Base Model are embedded into the initial inventory, and an additional constraint is imposed to prohibit any further emergency or spot purchases during the planning horizon. In this way, the Modified Base Model preserves feasibility while removing emergency procurement as a response option during subsequent analyses.

4.2.1 Results

The Modified Base Model remains feasible under the same underlying network structure, with the key difference that emergency RM purchases are treated as part of the starting inventory. As a result, the objective value is like that of the Base Model. This confirms that the Modified Base Model is not intended to represent a new operating design, but rather a normalized baseline from which disruption scenarios can be evaluated without the masking effect of reactive purchasing.

4.2.2 Implications

The Modified Base Model is methodologically important because it prevents disruption scenarios from being resolved through emergency buying. Otherwise, it would make the disruption appear less severe, understate revenue at risk, and make mitigation options seem more effective than they actually are. For this reason, all subsequent disruption scenarios are evaluated on the Modified Base Model so that their outcomes can be interpreted as structural resilience gaps.

4.3 Scenario 1 (Plant 2 Shutdown)

This scenario evaluates the resilience of the Tempur-Pedic network under a temporary shutdown of Plant 2 using the Modified Base Model. Three disruption durations were tested: three, six, and nine weeks of outage based on TSI's recommendations. Unlike supplier-side disruptions, which primarily constrain material availability, a plant shutdown tests whether the network can continue serving demand through production reallocation, inventory coverage, and logistics flexibility. In that sense, this scenario is less a material-shortage problem and more a test of how effectively the network and downstream flows can adapt when one manufacturing node becomes unavailable.

4.3.1 Scenario Implementation

The disruption is modeled as a complete shutdown of Plant 2 during the specified outage window. As a result, Plant 2 cannot produce finished goods or handle inbound and outbound flows during the affected weeks. All other network elements remain unchanged, allowing the optimizer to respond by shifting production to other plants and rebalancing flows across the network.

To measure the impact of disruption, the model tracks two key outcomes. First, unmet demand is recorded as lost sales, allowing service shortfalls to be quantified. Second, safety stock violations are tracked, allowing inventory safety stock to dip to maintain the service level during the disruption. The model also permits inter-DC transfers, enabling inventory repositioning across the distribution network when local shortages emerge. Together, these mechanisms allow the scenario to capture not only whether the network fails, but also the amount of operational strain absorbed to avoid failure.

4.3.2 Results

Across all three outage durations, the model maintains full service with no lost sales under the normalized FG safety stock. This suggests that the network can absorb a temporary loss of Plant 2 without an immediate gap in fulfillment. However, the absence of lost sales should not be interpreted as the absence of disruption. Service is preserved by depleting inventory, reallocating production, and using network flexibility to rebalance supply. In other words, the disruption does not disappear; it is absorbed elsewhere in the system. The network remains feasible, but only by relying more heavily on FG buffers and downstream coordination.

The key insight, therefore, is that plant-side disruptions primarily create an execution burden rather than an immediate service failure. As a disruption's duration increases, the system must work harder to preserve performance, making inventory depletion and rebalancing efforts more important indicators than lost sales alone. For the nine-week disruption case, holding two additional weeks of FG safety stock increases overall cost by approximately $2.7 million while reducing displacement costs by approximately $1.0 million. In the plant-closure tradeoff, every $1.0 million increase in safety stock penalty is associated with a $1.4 million reduction in transfer cost, indicating that holding more FG inventory reduces the operational burden of rerouting and inter-DC rebalancing during prolonged plant outages.

4.3.3 Implications

From a resilience perspective, these results show that FG safety stock provides meaningful protection against temporary plant outages. It acts as a bridge, helping the system maintain service while production is shifted and flows are rebalanced elsewhere in the network. This reinforces the broader conclusion that FG inventory is one of the most effective, broad resilience levers in the first months of a disruption.

At the same time, the scenario shows that inventory alone is not enough. The ability to maintain service depends on whether the network can operationalize that protection through flexible execution, specifically through alternate plant support, production reallocation, and inventory repositioning across distribution

nodes. Plant-side resilience, therefore, depends not only on buffer levels but also on the network's capability to move and reassign supply quickly when a production node is disrupted.

A final implication is that safety stock violations should be interpreted as an early warning of vulnerability, even when lost sales remain at zero. A network that continues to meet demand may still suffer if it consumes too much of its coverage in the process. For that reason, plant-shutdown resilience should be evaluated not only in terms of whether customer service is preserved, but also in terms of the inventory and execution effort required to maintain it.

4.4 Scenario 2 (Multi-sourced raw material disruption)

This scenario evaluates the resilience of the network under the disruption of an RM sourced from multiple suppliers. The analysis was conducted using the Modified Base Model, and three disruption durations were tested, corresponding to three, six, and nine weeks of supplier shutdown. This scenario was selected to examine a relatively moderate form of upstream supply risk. In contrast to a single-sourced material disruption, a multi-sourced disruption allows the network to assess the degree of resilience already embedded before additional mitigation is considered.

4.4.1 Scenario Implementation

The disruption is implemented as a temporary shutdown of supplier S501 supplying RM39 during the designated disruption window. The procurement of RM39 from this supplier is forced to zero for the affected weeks, while all other suppliers, plants, capacities, lead times, inventory balances, and demand conditions remain unchanged. This preserves the baseline network structure and allows the optimization model and decision-makers to respond through alternative sourcing, available inventory, and downstream network adjustments, where feasible.

As in the other disruption scenarios, the model tracks the disruption's impact through explicit measures. Lost sales are captured in the demand-satisfaction constraint, with unmet demand penalized at $1,000 per unit. Safety stock violations are allowed and penalized at $5 per unit. The model also permits inter-DC FG transfers, penalized at $50 per unit. These features ensure that the scenario captures not only service disruption, but also whether the disruption leads to inventory depletion or rebalancing effort.

4.4.2 Results

Across all three disruption durations, the network remains fully resilient under the modeled assumptions. No lost sales, safety stock deficits, or inter-DC transfers are observed. This indicates that shutting down one supplier of RM39 does not create measurable service degradation when the material remains available from alternative sources and the system continues to operate with the available FG safety stock.

The results further show that the disruption has only a negligible effect on overall system economics and network behavior. Cost patterns remain highly stable across the three cases, and the scenario does not trigger any meaningful change in downstream rebalancing activity. The latter suggests that the loss of supplier S501 is absorbed primarily through upstream sourcing substitution rather than through costly operational adjustments elsewhere in the network. In other words, the disruption does not propagate into broader system stress because the existing sourcing structure already provides sufficient buffer to maintain continuity. This finding is important because it demonstrates that the network is not simply coping with the disruption but is structurally capable of absorbing it, given the existing network of backup vendors that TSI relies on.

4.4.3 Implications

This result has direct implications for mitigation prioritization. Specifically, it suggests that not all RM require the same level of safety stock. For multi-sourced materials with adequate substitute capacity, the existing supply base may already provide enough resilience to absorb temporary supplier outages without

requiring significant incremental investment. More broadly, the scenario reinforces one of the central conclusions of the project: RM and FG buffers address different failure modes. Finally, Scenario 2 provides an important contrast to the single-sourced disruption analyzed in the following section.

4.5 Scenario 3 (Single-sourced raw material disruption)

This scenario evaluates the network's resilience to the disruption of a single-source RM. The analysis focuses on RM5 and uses the Modified Base Model. Three disruption durations (three, six, and nine weeks) were tested to examine how the network behaves as upstream material unavailability becomes more severe. This scenario is particularly important because, unlike the multi-sourced case, it removes sourcing redundancy and therefore directly tests the network's exposure to upstream material risk.

4.5.1 Scenario Implementation

The disruption is implemented as a shutdown of the sole supplier for RM5 during the designated disruption window. Under this setup, procurement of RM5 from its only source is forced to zero for the affected weeks, while all other conditions remain unchanged. This isolates the effect of an upstream material disruption while allowing the optimizer to respond through existing RM and FG inventory and network reallocation, where feasible. The scenario is evaluated under the normalized FG safety stock distribution. As in the previous scenarios, lost sales and safety stock violations are tracked. The model also permits inter-DC transfers, so the results capture not only whether service is preserved, but also the extent to which the system must draw down inventory and rely on network flexibility to respond.

4.5.2 Results

The single-sourced RM5 disruption exhibits fundamentally different behavior compared to plant closures and multi-sourced supplier disruptions. In this case, service levels begin to deteriorate once the disruption duration exceeds the protection provided by the FG inventory. Lost sales occur when the disruption outlasts the available weeks of FG safety stock plus RM safety stock, highlighting the importance of inventory against upstream material failures.

The trade-off analysis further shows that RM and FG buffers are not interchangeable. Increasing RM safety stock reduces lost sales, but with diminishing returns. The largest marginal benefit is achieved by maintaining approximately 20% additional RM inventory for critical materials, while further increases provide limited incremental value. At the same time, FG inventory remains essential. Even with RM safety stock at 100%, reductions in FG inventory led to worse performance. The nine-week disruption scenario further illustrates this insight. Increasing the FG inventory by two weeks, valued at approximately $10 million, avoids nearly three times that amount in lost sales and improves service levels by roughly 4%. Overall, these results demonstrate that FG inventory is the most effective lever for preserving service, outperforming broad increases in RM protection alone.

4.5.3 Implications

From an investment perspective, this scenario identifies one of the network's most important upstream vulnerabilities: its dependence on single-source, system-critical raw materials. Resilience should be evaluated in terms of marginal protection rather than maximum inventory across all materials. The results suggest that a modest increase in RM safety stock for the right materials can materially reduce lost sales, while excessive raw material coverage offers diminishing returns. By contrast, reducing the FG inventory leads to a sharper deterioration in service level. For TSI, this supports a differentiated inventory strategy: maintain at least the current FG inventory and add targeted RM protection for single-sourced materials with high risk exposure.

4.6 Limitations

Although the strategic findings are useful for TSI and other organizations, the results presented in this section should be interpreted with several modeling and data limitations in mind. First, the analysis is based on a deterministic multi-period MILP structure, meaning that demand, lead times, disruption timing, and recovery duration are treated as fixed within each scenario rather than as stochastic. While this is appropriate for scenario comparison, it does not fully capture the uncertainty and compounding variability that may arise in actual operations. As a result, the model is best interpreted as a decision-support tool for comparing structural vulnerabilities and mitigation levers, rather than as a precise predictor of disruption outcomes.

Second, the disruption scenarios were intentionally scoped to isolate specific failure modes, such as plant shutdowns, multi-sourced RM disruptions, and single-sourced RM disruptions. This improves interpretability, but it also means that the model does not capture simultaneous or correlated disruptions. In practice, supply chain failures may occur in overlapping ways, such as a supplier outage coinciding with a transportation disruption or a prolonged plant shutdown.

Third, several assumptions were required to make the model tractable and consistent across scenarios. These include standardized lead times, initialized inventory conditions, and penalty-based representations of lost sales, safety stock violations, and inter-DC transfers. Although these assumptions were developed using the sponsor's inputs and best available data, they simplify real operating behavior. For example, penalty costs provide a practical way to quantify unmet demand and buffer depletion, but the selected values influence how the model prioritizes trade-offs across service, inventory, and logistics. Similarly, the use of initial inventory normalization in the Modified Base Model improves the baseline for scenario testing, but it remains an abstract representation of how emergency procurement would unfold in practice.

Fourth, the analysis is limited by the quality and structure of the available data. The modeling process required substantial data preparation, including facility standardization, aggregation of storage and inventory positions, and conversion of sponsor-provided files into model-ready input tables. As with any large-scale network model, inaccuracies or omissions in source data may affect the precision of the outputs. In addition, it is difficult to fully represent some operating realities, such as local execution constraints, short-term scheduling decisions, or informal workarounds used during disruptions, in a strategic optimization model.

Finally, the project focuses on a specific product family and a defined network configuration over a bounded planning horizon. The results, therefore, should not be interpreted as a universal prescription for all products, facilities, or time periods within the sponsor's broader supply chain. Instead, the findings are most valuable as a directional framework for identifying where resilience investments are likely to generate the highest marginal benefit and for guiding more targeted follow-on analysis. Despite these limitations, the model provides a structured and decision-relevant basis for comparing disruption exposure and mitigation priorities across the network.

5. Conclusions and Recommendations

Using a multi-period MILP model, disruption scenarios, and inventory trade-off analysis, this capstone compared how different resilience levers perform under plant-side and supplier-side disruptions. The results show that risk-mitigation investments should not be distributed uniformly across the network. FG inventory emerged as the broadest protective lever across both disruption families, while targeted RM inventory, logistics flexibility, and alternate plant support provide complementary resilience for specific risk exposures.

5.1 Management Recommendations

Tempur Sealy could adopt a differentiated resilience strategy rather than pursuing broad inventory expansion across all nodes and materials. The main managerial insight is that RM inventory and FG inventory serve different purposes. FG inventory protects customer service by preserving service during disruption and absorbing downstream shocks, while RM inventory ensures production continuity. Because these two levers address different failure modes, they should be deployed selectively rather than treated interchangeably. The frontier analysis (Figure 2) further reinforces this recommendation. In the figure, the efficient frontier is the set of orange points connected by the blue line. These policies provide the best tradeoff between total cost and lost sales. The remaining policies, shown as blue points above the frontier, are dominated, meaning that another policy exists that delivers lower cost, lower lost sales, or both. Therefore, these policies are sub-optimal from a managerial perspective.

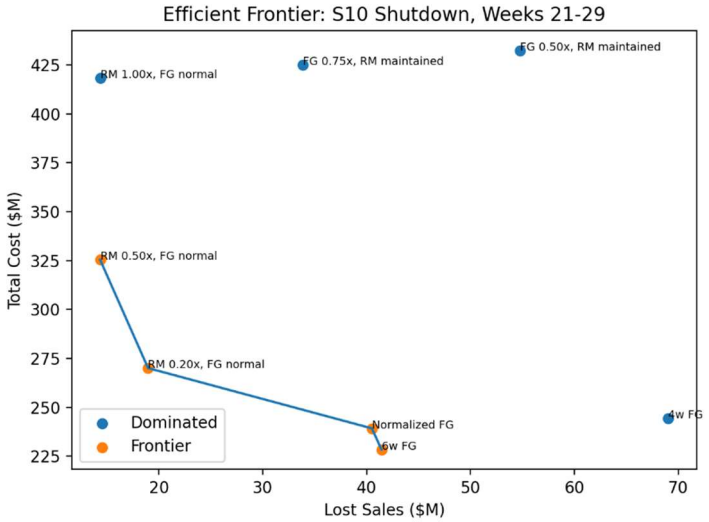


Figure 2. Efficient Frontier of RM and FG Inventory Strategies under S10 Shutdown

TSI can prioritize five risk-mitigation investments, ranked by impact, to increase supply chain resilience. First, the company should prioritize FG inventory as its primary resilience lever. Across all disruption scenarios, this proved to be the most effective lever for preserving service. Reductions in FG safety stock caused service deterioration more quickly than comparable reductions in RM inventory. The results also suggest that increasing FG inventory to about 1.2 times current levels is 40% more effective at mitigating lost sales than an equivalent increase in raw materials inventory. This makes FG inventory the clearest resilience lever for protecting revenue on a premium product line, especially when stockouts result in immediate lost sales and customer dissatisfaction.

Second, TSI should focus risk-mitigation efforts on single-source and system-critical materials rather than expanding buffers broadly across the network. Our analysis shows that RM inventory is valuable, but full protection appears excessive relative to the service improvement achieved. The more effective approach is to identify critical RMs with concentrated supplier dependency and maintain targeted safety stock spanning multiple weeks, ideally combined with finding secondary suppliers where feasible.

Third, TSI should strengthen execution resilience through outbound logistics and DC reallocation flexibility. The plant shutdown scenarios show that plant-side disruptions do not immediately cause service collapse when the network can reroute supply, shift production to other plants, and reposition inventory across the network. In these cases, the system remains serviceable but becomes more operationally strained. This

means that logistics flexibility is not merely an efficiency lever; it is a resilience capability that determines whether the network can convert existing inventory into actual sales during a disruption.

Fourth, TSI should improve inbound raw material flexibility by expanding the ability to hold external inventory and divert materials to alternative plants. The analysis indicates that RM inventory becomes more valuable when it is paired with the flexibility to be repositioned across the network. External storage, alternative routing, and supplier flexibility to serve multiple plants can materially improve resilience during disruption periods, especially when demand patterns and plant utilization vary over time.

Fifth, TSI should expand cross-training across its manufacturing network so that all plants can produce the full product portfolio. Considering common raw materials and similar work flows, TSI could further expand their production capability to replicate product lines, thus manufacturing all mattress variations across all plants. While the results indicate that this capability helps absorb the impact of plant outages, its effectiveness is contingent on the presence of the previously identified levers.

These recommendations also fit the company's broader direction. In its latest financial report, Tempur Sealy International emphasized execution, operational efficiency, and long-term profitable growth as business priorities (TSI, 2026). In that context, the recommendations from this project are not just defensive measures. They support those goals by helping the company maintain service levels, use working capital more effectively, and reduce exposure to disruption as demand continues to grow. Rather than expanding inventory broadly across the network, the results point to a more disciplined investment approach: maintain strong FG protection where it most directly supports revenue and customer service, add RM protection selectively for critical materials, and strengthen the logistics and network capabilities that enable effective inventory deployment during disruption.

5.2 Future Work

Several next steps could strengthen the practical value of this work. First, future analysis should test compound and correlated disruptions, such as simultaneous supplier, plant, and transportation failures, since real-world disruptions may interact in ways that deplete resilience faster than isolated scenarios suggest. Second, the model could be enhanced by incorporating stochastic demand, lead times, and recovery durations, enabling the evaluation of mitigation strategies across a wider range of uncertainties rather than under fixed-scenario assumptions. Third, the framework could be extended into a probability-weighted investment roadmap by linking each mitigation option to implementation cost, expected reduction in revenue-at-risk, and likely disruption frequency. This would help translate the current prioritization into a phased investment plan. Finally, the methodology could be applied to additional products and refreshed periodically with updated sourcing, inventory, capacity, and demand data so that TSI can use it as an ongoing decision-support tool for resilience planning rather than as a one-time analysis.

In a broader context, this study demonstrates that resilience investments should not be evaluated as isolated buffers or standalone capabilities. Their value depends on how they interact across the E2E network and on which failure mode they are intended to protect against. For manufacturers facing similar tradeoffs between service, working capital, and disruption exposure, the framework developed in this project provides a structured way to identify which resilience levers generate the highest marginal benefit and where protection is likely to be excessive.

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