Supply Chain Vulnerability in the Indian Pharmaceutical Industry: With Special Reference to Logistics and Inventory Management

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Abstract

We investigate the perception on the severity and probability of key logistics and inventory management risks within India's pharmaceutical supply chain, drawing insights from quantitative data and stakeholder perceptions. We assess the perception on seven major supply chain risks - demand forecasting error, counterfeit products, warehousing issues, customs clearance delays, transportation delays, theft during transit and warehousing, and cold chain temperature excursions.

We have conducted a survey of 151 respondents involved in the supply chain function of Indian Pharma Companies. The results indicate that demand forecasting error emerged as the most critical risk in terms of severity and probability. Counterfeit risks and theft also ranked high, reflecting concerns over product integrity and supply chain security. ANOVA analysis revealed that while severity perceptions were largely consistent across small, medium, and large organizations, probability ratings varied significantly, particularly for transportation delays and counterfeit risks. Warehousing issues, though moderate in severity, were perceived as highly probable, indicating widespread operational inefficiencies.

Our findings implicate the need for differentiated risk mitigation strategies, including advanced forecasting tools, secure logistics infrastructure, and regulatory streamlining. By identifying and analysing these vulnerabilities, our study offers actionable insights for pharmaceutical managers aiming to enhance supply chain resilience, safeguard product quality, and ensure timely delivery in a complex and evolving market landscape.

Keywords:

Pharmaceutical supply chain, logistics risks, demand forecasting, counterfeit products, inventory management

JEL Classification:
L65, L91, M11, D81, I18

INTRODUCTION

India's pharmaceutical industry is a cornerstone of domestic and global healthcare supply chains. As of 2025, the market is valued at USD 66.66 billion and is projected to reach USD 88.86 billion by 2030, growing at a compound annual growth rate (CAGR) of 5.92% (mordorintelligence, 2025). A dual engine of domestic consumption and export demand

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drives the sector. India supplies over 50% of global vaccine requirements and 40% of generic drugs consumed in the United States. According to the India Brand Equity Foundation (IBEF), the domestic pharmaceutical market is expected to reach USD 57 billion by FY2025. At the same time, the total industry, including exports, is projected to hit USD 130 billion by 2030 (IBEF, 2025). The government's Production Linked Incentive (PLI) scheme, with an outlay of INR 15,000 crore (USD 2.04 billion), is designed to boost manufacturing capacity and reduce dependence on imported Active Pharmaceutical Ingredients (APIs), particularly from China. In H1 FY2025 alone, INR 604 crore (USD 69.76 million) was disbursed under this scheme to support bulk drug production and infrastructure upgrades (IBEF, 2025). Therapeutically, anti-infectives dominate with a 19.6% market share, while oncology drugs are the fastest-growing segment, projected to expand at a CAGR of 7.10% through 2030. Statista reports that oncology alone is expected to generate USD 2.06 billion in revenue in 2025, underscoring the rising burden of chronic diseases and the shift toward speciality therapies (Statista, 2025). Distribution remains anchored in retail pharmacies, which account for 75% of the market, though online channels are multiplying at a CAGR of 7.3%, driven by digital adoption and urban demand. The oral route of administration holds 62% of the market, but injectables are gaining ground due to the rise of biologics and sterile manufacturing, with a projected CAGR of 6.5% . Regionally, North India leads with 33% of market share, while Northeast India is the fastest-growing zone at 6.4% CAGR.

Foreign direct investment (FDI) in the pharmaceutical sector reached INR 2,00,166 crore (USD 23.41 billion) between April 2000 and March 2025, reflecting investor confidence in India's long-term potential. These figures collectively highlight the sector's robust growth trajectory, strategic importance, and the urgent need for resilient supply chains and logistics frameworks to sustain its momentum.

India's pharmaceutical industry is globally recognised for its scale, affordability, and export capacity. As the world's largest provider of generic medicines and a major supplier of vaccines, India plays a pivotal role in global healthcare. However, a complex and increasingly fragile supply chain ecosystem lies beneath this success. The COVID-19 pandemic exposed critical vulnerabilities in sourcing, manufacturing, and distribution, particularly due to India's heavy dependence on imported Active Pharmaceutical Ingredients (APIs), primarily from China.

The pharmaceutical supply chain in India is characterised by a multi-tiered structure involving raw material suppliers, formulation manufacturers, contract development and manufacturing organisations (CDMOs), distributors, and retailers. While this structure enables scalability and cost efficiency, it also introduces systemic risks ranging from geopolitical disruptions and regulatory bottlenecks to logistical inefficiencies and quality control lapses. For instance, over 70% of India's API requirements are met through imports, making the industry susceptible to external shocks such as trade restrictions or global price fluctuations (Corona Remedies, 2025).

Moreover, the increasing complexity of pharmaceutical products, especially biologics and speciality drugs, demands more stringent cold chain logistics, advanced manufacturing capabilities, and regulatory compliance. These requirements amplify risk exposure across the supply chain, particularly for small and mid-sized enterprises that lack the infrastructure to adapt swiftly. The rise of e-pharmacies and digital health platforms has further transformed distribution dynamics, introducing new cybersecurity and data integrity risks.

In this context, supply chain resilience is no longer a peripheral concern but a strategic imperative. Risk management frameworks tailored to the pharmaceutical sector must account for operational and strategic risks, including supplier reliability, regulatory compliance, demand forecasting, and technological disruptions. The Indian government's Production Linked Incentive (PLI) scheme and initiatives like Ayushman Bharat aim to strengthen domestic manufacturing and healthcare access. However, their long-term impact on supply chain stability remains to be fully assessed.

The Indian pharmaceutical supply chain, despite its global prominence, faces a multitude of operational and strategic risks that threaten its reliability and efficiency. Among the most pressing concerns are transportation delays, which stem from overreliance on road networks plagued by poor infrastructure, traffic congestion, and limited connectivity in rural regions. These delays can disrupt the timely delivery of essential medicines, particularly in Tier-2 and Tier-3 cities (mordorintelligence, 2025). Warehousing issues further compound these challenges, as many facilities lack adequate space, automation, and environmental controls, leading to inventory mismanagement and product degradation. Cold chain temperature excursions are especially critical for biologics and

vaccines, where even minor deviations can compromise efficacy. According to ExpressPharma (2025), nearly 20% of temperature-sensitive pharmaceutical products in India are exposed to improper handling during transit or storage. Customs clearance delays also pose significant risks, particularly for imported Active Pharmaceutical Ingredients (APIs), which constitute over 70% of India's API consumption. Regulatory bottlenecks and inconsistent documentation requirements across ports can lead to prolonged clearance times and production halts (IBEF, 2025). Theft during transit and warehousing is another growing concern, especially for high-value or controlled substances. (KPMG, 2025) reports that pharmaceutical theft and diversion incidents have increased in recent years, often linked to gaps in third-party logistics oversight. Counterfeit drugs, facilitated by fragmented distribution channels and weak enforcement mechanisms, not only threaten patient safety but also erode brand trust and market share. The World Health Organisation estimates that up to 10% of medicines in low- and middle-income countries may be substandard or falsified. India is a key target due to its vast and decentralised supply network. Lastly, demand forecasting errors-driven by limited access to real-time data, seasonal variability, and unpredictable disease outbreaks - can result in stockouts or overproduction, straining financial and operational resources. These risks underscore the urgent need for integrated risk management frameworks, digital supply chain visibility, and regulatory harmonisation to enhance resilience and ensure uninterrupted access to quality medicines.

The COVID-19 pandemic subjected healthcare supply chains to unprecedented stress, exposing significant vulnerabilities in risk preparedness. With limited prior knowledge or established frameworks to address such large-scale disruptions, risk managers faced considerable uncertainty. The severe challenges of demand surges, stockouts, and bullwhip effects highlighted the vital role of resilience in ensuring continuity and reliability of healthcare product supply chains(Gupta & Kayande, 2023).

This paper seeks to critically examine the vulnerabilities embedded within the Indian pharmaceutical supply chain and propose a structured risk management approach to mitigate them. By integrating insights from industry reports, policy frameworks, and supply chain theory, the study aims to offer actionable recommendations for enhancing resilience and ensuring uninterrupted access to essential medicines.

PREVIOUS STUDIES

The pharmaceutical supply chain (PSC) has received increasing scholarly attention, particularly considering global disruptions such as the COVID-19 pandemic. Several studies have explored the nature, classification, and mitigation of risks within pharmaceutical logistics and operations, offering diverse methodological approaches and regional perspectives. (Azam et al., 2023) have conducted a systematic literature review to identify and prioritise critical success factors (CSFs) for resilient supply chains in SMEs. Using principal component analysis, they highlighted key CSFs including strategic partnerships, technology use, and capacity building to address uncertainty and enhance preparedness. Similarly, post COVID-19, Čerkauskienė & Meidute-Kavaliauskiene, (2023) have explored the key aspects of supply chain risk management in healthcare and identified the critical factors influencing supply chain performance and highlighted the need for improved risk assessment and resilience strategies in healthcare systems. An investigation of pharmaceutical supply chain resilience through focus groups with global stakeholders, conducted by Faggioni et al. (2023), reveals consensus on key resilience elements - adaptability, flexibility, agility, and collaboration.

In an examination of key resiliency strategies for pharmaceutical supply chains (Ganguly & Kumar, 2019) have used the Fuzzy Analytic Hierarchy Process to show that agility, visibility, and collaboration are top priorities for mitigating supply chain vulnerabilities, offering actionable insights for managers and policymakers in resilience planning.

The key drivers of resilient supply chains in India's pharmaceutical sector to enhance sustainable exports are manufacturing excellence, reverse logistics, and distribution as critical enablers, with sourcing and R&D supporting resilience through improved export performance and strategic socio-economic interventions(Gera & Singh, 2025).

Jaberidoost et al., (2015) have conducted a multi-phase risk assessment of Iran's pharmaceutical supply chain, identifying 86 risks across 11 categories. Financial and economic risks dominated, with financial management deemed most critical. Despite political challenges, half of the risks were internal and potentially manageable by pharmaceutical companies. (Pathy & Rahimian, 2023) present a two-stage optimisation framework to manage demand uncertainty in pharmaceutical supply chains. The first stage minimises prepositioning costs and risks at

distribution centres, while the second reduces costs of recourse actions like reallocation and inventory management, enhancing overall supply chain efficiency.

An examination of supply chain resilience in the Indian manufacturing sector, particularly key antecedents like risk management culture, connectivity, visibility, collaboration, and agility, shows that ICT adoption and employee awareness can help enhance resilience and firm performance(Kumar & Anbanandam, 2020). Merkuryeva et al., (2019) have focused on using advanced demand forecasting methods in the pharmaceutical supply chain, presenting an integrated approach for product forecasting and purchase order generation. Through a case study, they evaluate SMA, multiple linear regression, and symbolic regression models, highlighting the practical implications in emerging markets. Some authors have proposed a blockchain-based infrastructure to enhance traceability and security in the pharmaceutical supply chain(Mishra et al., 2024)Their model combats record forgery and counterfeit drugs using smart contracts and parallel search techniques. Theoretical and simulation analyses confirm its efficiency and practical viability.

Özdoğan & Mulgan, (2024) have examined healthcare logistics, emphasising its role in managing materials, services, and data to enhance care delivery. They highlight flexibility as a key component in overcoming disruptions like COVID-19, and stress the importance of coordinated supply chain strategies for improved healthcare system performance.

The sub-optimal sales and operations planning exaggerates the critical risks - inventory planning, labour, storage, raw material availability, forecasting, and communication(Sangode, 2024). The global threat of counterfeit products in the growing medical device and pharmaceutical industries essentially requires a holistic approach involving robust healthcare systems, reliable data, international cooperation, and digital tracing technologies to mitigate risks and enhance supply chain integrity(Syed & Milburn, 2024). Based on the SWOT analysis of India's pharmaceutical supply chain, strategic interventions to enhance SCM performance, aiming to strengthen global competitiveness and operational resilience, have been proposed by (Wahab et al., 2024). A fuzzy AHP-based MCDM framework to identify and prioritise 24 risks in India's pharmaceutical supply chain has been proposed by Vishwakarma et al. (2016). Their analysis highlights supply and supplier risks as most critical, offering valuable insights for mitigating disruptions and enhancing healthcare system effectiveness through robust risk assessment.

Recent academic studies have identified critical logistics and inventory management risks in the Indian pharmaceutical industry, including counterfeit drugs, demand fluctuations, and cold chain failures (Sharma et al., 2024). However, a significant research gap remains in developing integrated, technology-driven frameworks for real-time risk mitigation. Existing literature often focuses on isolated risk factors without addressing systemic vulnerabilities or the role of digital tools like blockchain and AI in enhancing supply chain resilience. Despite the growing importance of logistics and inventory management in the Indian pharmaceutical industry, academic research over the past decade reveals a limited focus on quantifying and mitigating supply chain risks. We find a gap in the context of an underdeveloped comprehensive framework for risk prioritisation. Weak distribution networks and inadequate inventory systems continue to hinder operational efficiency in the Indian pharmaceutical industry.

MATERIALS AND METHODS

Our study has employed a quantitative research design supported by primary and secondary data sources to assess logistics and inventory-related vulnerabilities in the Indian pharmaceutical supply chain. We adopt a quantitative research approach, grounded in primary data collection through a structured survey administered to employees working in pharmaceutical companies across India. We aim to obtain respondents' perceptions of supply chain risks, with particular attention to logistics vulnerabilities.

We initially conducted a pilot survey to identify the prominent risks in the logistics and inventory context in the supply chain in the Indian pharmaceutical industry for content validity. We have formulated a questionnaire comprising three sections based on the pilot survey results and industry experts. Section A seeks information on the organisation profile of the respondents – level of management in the supply chain, size of the organisation, drug segment, and type of market segment by disease type. Section B has explored the opinions on the perception of risk severity and probability for seven defined classes of Logistics and Inventory Management Risks on a Likert scale. Section C explores the respondents' general perception of the evolving risks in the supply chain in the Indian pharmaceutical industry.

The key logistics and inventory risks have been classified into (a) demand forecasting errors, (b) counterfeit products, (c) warehousing inefficiencies, (d) customs clearance delays, (e) transportation delays, (f) theft during transit and storage, and (g) cold chain temperature excursions. We have used a purposive sampling method to target professionals with direct experience in logistics and inventory management. Out of the 180 individuals contacted, 151 valid responses have been received. The demographic profile of respondents reflects that the majority were mid-level managers with six to ten years of professional experience, predominantly working in large-scale pharmaceutical organisations. We use descriptive and inferential statistical methods to obtain the results. The reliability of the questionnaire has been tested using Cronbach's alpha (0.839). We have used one-way ANOVA to examine differences in severity and probability perception of logistics and inventory-related vulnerabilities across organisations' selected parameters. The qualitative results are supported with secondary data from policy documents, government reports, and prior academic studies to contextualise findings and enhance triangulation.

RESULTS AND DISCUSSION

Respondents are predominantly male, representing 95.4% of the total sample. Regarding organisational size, 60.7% of the respondents are employed in large enterprises, 26.1% in medium-sized firms, and 13.2% in small organisations. Our findings primarily represent large-scale pharmaceutical operations with more complex and expansive supply chains. Our sample is polarised towards mid-tier decision-makers, with limited representation from frontline staff and executive leadership, a limitation of the study. The sample is predominantly middle-aged, with 66.8% of participants in the 31–40-year bracket. Respondents aged 41–50 accounted for 17.9%, while those aged 21–30 represented 14.6%. Only 0.7% of the sample was above 50, suggesting limited input from senior professionals nearing retirement age.

Regarding market engagement, 75.4% of respondents reported involvement in branded and generic drug segments, while only 24.6% focused exclusively on branded products. Similarly, 96.7% of participants indicated engagement with general and specialised drug types, suggesting a broad therapeutic footprint across the sample.

Tables 1 and 2 present the risk severity and probability results for the formulated risk categories.

Table 1: Risk Severity - Logistics and Inventory Management Risks

Risk Category	Very less severe (%)	Somewhat severe (%)	Severe (%)	Very severe (%)	Extremely severe (%)
Demand Forecasting Error Risk Severity	1.3	2.6	13.2	23.8	58.9
Counterfeit Risk Severity	3.3	4.6	11.3	29.1	51.7
Theft during Transit & Warehousing Severity	2.0	5.3	14.6	34.4	43.7
Customs Clearance Risk Severity	0.7	2.6	17.9	36.4	42.4
Cold Chain Temperature Risk Severity	3.3	2.0	15.9	39.7	39.1
Warehousing Issues Risk Severity	2.0	3.3	9.9	42.4	42.4
Transportation Delays Risk Severity	2.6	3.3	13.9	37.7	42.4

Source: Author's Computation

It is inferred that among the seven risks analysed, demand forecasting errors emerged as the most severe, with 58.9% of respondents rating it as “extremely severe.” This highlights the disruptive impact of inaccurate projections on inventory planning and service delivery. Counterfeit risks and theft during transit and warehousing also ranked high, reflecting concerns over product integrity and security. Customs clearance delays and cold chain temperature excursions were viewed as moderately severe, indicating persistent operational bottlenecks, especially for temperature-sensitive drugs. Warehousing issues and transportation delays showed a more balanced severity distribution, but cumulative impact remained significant. The data suggests that forecasting, security, and authenticity are top priorities for risk mitigation. These findings underscore the need for robust analytics, secure logistics protocols, and regulatory streamlining to enhance resilience in India's pharmaceutical supply chain.

Table 2: Risk Probability - Logistics and Inventory Management Risks

Risk Category	Very less probable (%)	Somewhat probable (%)	Probable (%)	Very probable (%)	Extremely probable (%)
Demand Forecasting Error Risk Probability	2.6	1.3	22.5	24.5	49.0
Counterfeit Risk Probability	3.3	1.3	22.5	30.5	42.4
Theft during Transit & Warehousing Probability	4.0	5.3	24.5	24.5	41.7
Customs Clearance Risk Probability	2.6	6.0	24.5	26.5	40.4
Cold Chain Temperature Risk Probability	3.3	7.9	18.5	39.7	30.5
Warehousing Issues Risk Probability	4.6	6.6	15.9	37.7	35.1
Transportation Delays Risk Probability	4.0	4.0	20.5	37.7	33.8

Source: Author's Computation

Table 2 reveals that demand forecasting errors stand out as the most critical, with nearly half (49%) of respondents rating it as extremely probable, indicating a significant concern for supply chain accuracy. Counterfeit risks and transportation delays also show a high likelihood, with a combined majority leaning toward very probable. Theft during transit, customs clearance issues, and cold chain temperature failures all present moderate to high risk, suggesting vulnerabilities in physical handling and regulatory processes. Interestingly, over 76% of respondents perceive warehousing issues as highly probable, underscoring operational inefficiencies. The relatively lower percentages in the very low and somewhat probable categories across most risks suggest that stakeholders view these challenges as persistent and pressing. The data reveals that across all categories, at least one-third of respondents rated risks as "extremely probable," implying the need for robust forecasting, secure logistics, technology adoption and streamlined operations to mitigate these risks effectively.

Table 3: Risk Severity and Risk Probability–Mean Comparison and ANOVA

Logistics and Inventory Management Risks	***Risks Severity***		***Risks Probability***	
	Mean	SD	Mean	SD
Demand Forecasting Error	4.364	0.905	4.159	0.994
Counterfeit	4.212	1.037	4.073	1.001
Warehousing Issues	4.199	0.895	3.921	1.093
Customs Clearance	4.172	0.862	3.960	1.064
Transportation Delays	4.139	0.959	3.934	1.031
Theft during Transit & Warehousing	4.126	0.982	3.947	1.112
Cold Chain Temperature	4.093	0.962	3.861	1.046

Source: Author's Computation

The analysis of logistics and inventory management risks reveals several key patterns in severity and probability ratings. Demand forecasting error emerges as the most critical among the various risks assessed. For the full sample, it has the highest mean severity score, indicating that it poses the greatest potential impact on operations. The relatively high standard deviation suggests variability in how this risk is perceived, likely influenced by differences in organisational forecasting capabilities, market volatility, and product types. Notably, demand forecasting error also ranks highest in probability, reinforcing its position as a dual threat—both highly impactful and likely to occur. This combination underscores the importance of prioritising mitigation strategies such as advanced predictive analytics, real-time data integration, and cross-functional planning.

Other risks exhibit high variability in probability, particularly theft during transit and warehousing. Although their mean probability scores are moderately high, the elevated standard deviations suggest inconsistent experiences across the supply chain. These inconsistencies may stem from contextual factors such as geographic location, product category, and the robustness of security protocols. For instance, high-value goods or regions with limited infrastructure may be more susceptible to theft, while counterfeit risks may vary depending on brand visibility and regulatory enforcement.

Cold chain temperature risk, while ranking lowest in severity and probability, still warrants attention. Its severity score remains above the threshold of concern, indicating that although it may not occur frequently, its impact can be substantial - particularly for temperature-sensitive products such as pharmaceuticals, biologics, and perishable food items. The relatively lower probability suggests that organisations may have implemented effective controls, yet the potential consequences of failure justify continued investment in monitoring technologies and contingency planning.

Overall, the findings highlight the need for differentiated risk management approaches. While demand forecasting error demands systemic and strategic interventions, risks with high variability require context-specific solutions. Despite their lower frequency, cold chain risks should not be overlooked due to their potentially severe consequences.

We have conducted a one-way ANOVA to examine the differences in respondents' perception across selected categories in the organisation demographics.

Table 4: ANOVA – Size of Organization

Risk Type	**Risk Severity F Ratio (Sig.)**	**Risk Probability F Ratio (Sig.)**
Transportation Delays	0.594 (0.553)	*4.536 (0.012)*
Warehousing Issues	1.685 (0.189)	1.827 (0.165)
Cold Chain Temperature	0.724 (0.487)	0.196 (0.822)
Customs Clearance	0.647 (0.525)	1.515 (0.223)
Theft during Transit & Warehousing	0.663 (0.517)	1.466 (0.234)
Counterfeit	0.123 (0.884)	*4.686 (0.011)*
Demand Forecasting	0.691 (0.503)	1.888 (0.155)

Source: Author's Computation

Table 5: ANOVA – Drug Segment

Risk Type	**Risk Severity F Ratio (Sig.)**	**Risk Probability F Ratio (Sig.)**
Transportation Delays	1.204 (0.302)	*2.982 (0.022)*
Warehousing Issues	2.031 (0.134)	2.267 (0.107)
Cold Chain Temperature	0.942 (0.392)	0.318 (0.729)
Customs Clearance	*3.118 (0.028)*	1.674 (0.191)
Theft during Transit & Warehousing	0.882 (0.417)	1.552 (0.210)
Counterfeit	0.276 (0.760)	*4.103 (0.008)*
Demand Forecasting	1.337 (0.264)	2.412 (0.093)

Source: Author's Computation

ANOVA results in Table 4 indicate that among the seven risk types analysed, Transportation Delays and Counterfeit show statistically significant differences in risk probability ($p < 0.05$) across organisation size, suggesting these risks are more likely to occur across varying conditions. None of the other risk types exhibits significant variation in risk severity($p>0.05$). This implies that while the likelihood of certain risks may differ, their perceived severity remains relatively consistent. This indicates the need for targeted mitigation strategies focused on high-probability risks. The findings also implicate the perception of the legal framework for transportation norms, which smaller firms ignore (Skyes, 2018).

In Table 5, ANOVA analysis reveals that Transportation Delays and Counterfeit risks show statistical significance across drug segments. Additionally, Customs Clearance significantly impacts risk severity, suggesting differences in perceived severity. In some studies, it has been established that 56% of the counterfeit drugs(generic) are manufactured in India(Feeney et al., 2024). All other risk types exhibit non-significant results ($p > 0.05$) for severity and probability, implying consistent perceptions and likelihoods across groups. These findings underscore the importance of prioritising mitigation strategies for risks with significant variation.

The results confirm prior research studies that show that transportation inefficiencies, regulatory delays, and counterfeit drugs are central vulnerabilities in pharmaceutical supply chains, particularly in emerging economies like India(Kumar & Anbanandam, 2020; Lima & Yonamine, 2023).

We draw the inferences from the results as follows.

Demand forecasting errors are the most critical and persistent vulnerability in the Indian pharmaceutical supply chain, both in terms of risk severity and risk probability, given that many respondents have rated this vulnerability as "extremely severe." The inventory mismatch creates a dual challenge of wastage and stockout in patient care. Such forecasting errors have been the root cause of inefficiencies in healthcare logistics and pharmaceutical distribution(Chopra & Meindl, 2012; Shukla & Jharkharia, 2013). We argue that using AI and other advanced tools may help address the vulnerability, particularly in the case of generic drugs.

Due to their larger brand presence and distribution networks, large firms face a higher risk of counterfeit medicines and transit theft threats. Furthermore, the disparity in likelihood assessments between firm sizes indicates that vulnerabilities are inconsistent: smaller firms perceive being more susceptible to delays, while larger organisations face a higher risk of counterfeiting (Emrouznejad et al., 2023).

Operational Bottlenecks in Customs and Cold Chain Management - Customs clearance delays and cold chain temperature excursions are viewed as moderately severe and probable. Although not the most critical, they represent persistent vulnerabilities, especially for temperature-sensitive pharmaceuticals(Shukla & Jharkharia, 2013). While severity perceptions are generally consistent across small, medium, and large organisations, probability ratings vary significantly. For example, transportation delays and counterfeit risks show statistically significant differences in probability, with smaller firms perceiving higher vulnerability to delays and larger firms more exposed to counterfeiting. Warehousing Issues as a Silent Burden, despite moderate severity scores, many respondents perceive warehousing issues as highly probable, indicating widespread operational inefficiencies that may not be immediately disruptive but cumulatively impact performance.

We suggest that pharmaceutical firms prioritise adopting AI-driven predictive analytics, real-time market data integration, and collaborative planning systems to enhance forecast accuracy and responsiveness. Pharma companies also need to strengthen Supply Chain Security Protocols and mitigate risks related to counterfeiting and theft. Managers should implement robust authentication technologies (e.g., blockchain, serialisation), enhance physical security measures, and conduct regular audits across transit and storage points.

For temperature-sensitive products, investment in IoT-enabled temperature tracking, contingency planning, and staff training is essential to prevent excursions and ensure regulatory compliance. Collaboration with regulatory bodies and logistics partners to simplify documentation, enable pre-clearance, and reduce bottlenecks can significantly improve delivery reliability and reduce delays.

Since probability perceptions vary by firm size, risk management strategies should be customised. Smaller firms may need support in infrastructure and logistics planning, while larger firms should focus on brand protection and regulatory alignment. Managers must not overlook warehousing issues due to their high probability. Investments in automation, inventory control systems, and workforce training can substantially improve operational efficiency.

CONCLUSION

The findings from this study underscore the multifaceted nature of logistics and inventory management risks within India's pharmaceutical supply chain. Demand forecasting error stands out as the most critical risk, consistently rated highest in severity and probability, reflecting its disruptive potential on inventory planning and service delivery. Counterfeit products and theft during transit also pose significant threats, particularly for larger organisations, highlighting vulnerabilities in product integrity and supply chain security. While risks such as customs clearance delays, transportation delays and cold chain temperature excursions are perceived as moderately severe, their operational impact remains substantial, especially for temperature-sensitive pharmaceuticals.

Interestingly, warehousing issues, though not rated as the most severe, are perceived as highly probable, suggesting widespread inefficiencies that may accumulate over time to affect overall performance. The analysis also reveals that while severity perceptions are relatively uniform across organisational sizes, probability ratings vary, indicating that firm size influences perceived exposure to certain risks.

These insights carry important managerial implications. To mitigate these risks effectively, organisations must invest in predictive analytics, secure logistics infrastructure, and regulatory streamlining. Tailored strategies based on organisational scale and operational context are essential. Enhancing supply chain resilience requires a proactive, data-driven approach integrating technology, compliance, and strategic foresight.

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