IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Supply Chain Management in the Pharmaceutical Industry: Operational Challenges, Technological Integration, and Strategies for Performance Enhancement

Sapna Dagduba Shinde[1], Asst.Prof .Shivaji Solunke[2]

[1]B.pharm Final year, Rajesh bhaiya Tope college of pharmacy.nipani bhalgaon, Maharashtra

[2]Assistant Professor, Department of Chemistry, Rajesh bhaiya Tope college of pharmacy.nipani bhalgaon, Maharashtra

ABSTRACT

Supply chain management (SCM) occupies a strategically critical position in the pharmaceutical sector, where product quality failures or distribution interruptions can translate directly into adverse patient outcomes. This paper presents a structured analysis of SCM practices within the Indian pharmaceutical industry, drawing on comparative observations from two representative organizations—Harman Finochem Limited, a leading Active Pharmaceutical Ingredient (API) manufacturer, and Sun Pharmaceutical Industries, a globally integrated formulations company. Using a descriptive-analytical research design supported by primary survey data and secondary financial and operational data, the study identifies persistent inefficiencies including siloed departmental functioning, inadequate outsourcing governance frameworks, and suboptimal digital integration. The cost architecture of pharmaceutical SCM is quantified: manufacturing accounts for the largest share (25%), followed by procurement, inventory management, and distribution (each 20%), with transportation contributing the remainder (15%). The study evaluates a portfolio of technological interventions—including Artificial Intelligence for demand sensing, blockchain-based track-and-trace, IoT-enabled cold chain monitoring, and ERP-integrated planning—and maps these against documented operational deficiencies. Key findings indicate that organizations adopting integrated digital SCM platforms demonstrate measurably superior performance in order fulfillment rates, inventory turnover, and regulatory compliance. The paper concludes by proposing a multi-dimensional SCM improvement framework aligned with Good Distribution Practice (GDP) standards and India's evolving regulatory landscape.

Keywords: *Supply Chain Management; Pharmaceutical Industry; Active Pharmaceutical Ingredients; Cold Chain Logistics; Blockchain Traceability; Demand Forecasting; Inventory Optimization; Digital Transformation; Sun Pharma; Harman Finochem*

1. INTRODUCTION

The concept of supply chain management was formally articulated by Keith Oliver in 1982, who described it as the management of a chain of supply as a unified entity rather than a collection of independent functions [1]. Over the four decades since, the discipline has matured from a logistics-centric operational concern into a foundational strategic competency that determines organizational competitiveness across virtually every industrial sector. In no industry, however, is the consequence of supply chain failure more immediately felt than in pharmaceuticals, where a shortage of a single essential medicine can precipitate avoidable patient morbidity or mortality.

The pharmaceutical supply chain encompasses an end-to-end value network that begins with the extraction or synthesis of raw chemical precursors and terminates at the patient receiving a dispensed dosage form. Between these endpoints lie multiple stages—API manufacturers, formulation plants, quality control laboratories, primary and secondary warehouses, national and regional distributors, wholesale stockists, hospital pharmacies, and retail dispensing points—each of which must operate within tightly specified quality, regulatory, and environmental parameters [2]. The complexity of managing this network is compounded by the biological sensitivity of many products (necessitating cold chain logistics), the stringent documentation requirements of regulatory agencies such as the Central Drugs Standard Control Organisation (CDSCO) in India and the Food and Drug Administration (FDA) in the United States, and the increasing prevalence of multi-tiered global sourcing that introduces geopolitical and logistical vulnerabilities.

India occupies a unique position in the global pharmaceutical supply chain. As the world's largest supplier of generic medicines by volume and a dominant manufacturer of APIs, Indian pharmaceutical companies simultaneously function as upstream suppliers to multinational corporations and as autonomous producers serving domestic and export markets. This dual role imposes competing pressures on supply chain design: cost efficiency demands that are characteristic of generic markets must be reconciled with the quality and reliability standards required for regulated Western markets [3]. The COVID-19 pandemic starkly exposed the fragility of single-source API procurement strategies, particularly India's dependence on Chinese intermediates, accelerating both industry and government interest in supply chain diversification and resilience [4].

Despite the acknowledged strategic importance of SCM, empirical research examining supply chain practices within Indian pharmaceutical organizations—particularly in comparison across different segments of the value chain—remains relatively limited. This study addresses that gap by conducting a structured comparative analysis of SCM practices at Harman Finochem Limited, which operates at the API manufacturing level, and Sun Pharmaceutical Industries, which operates across formulation, distribution, and global marketing. The study further seeks to identify the technological and process-level interventions most likely to produce measurable improvements in supply chain performance.

1.1 Scope and Significance

The present study is delimited to the supply chain operations of pharmaceutical manufacturing and distribution organizations within the Indian regulatory context, with reference to international best practices where relevant. The findings carry significance not only for organizational managers seeking operational improvements but also for healthcare system planners concerned with medicine availability, and for regulatory bodies designing oversight frameworks for pharmaceutical distribution.

2. LITERATURE REVIEW

A foundational contribution to supply chain theory is the work of Chopra and Meindl [5], who established that supply chain strategy must be explicitly aligned with competitive strategy, and that the decision variables of inventory, transportation, facilities, and information must be optimized collectively rather than individually. Their framework provides the analytical scaffolding for understanding why pharmaceutical supply chains—which must simultaneously minimize cost and maximize responsiveness—face inherent design tensions.

Christopher [6] extended this perspective by arguing that supply chain agility—the capacity to rapidly reconfigure resources in response to demand volatility—is particularly critical in sectors characterized by short product shelf lives and unpredictable demand patterns. Both conditions are endemic to pharmaceuticals, where demand spikes during disease outbreaks and the expiry dates of medicines impose hard constraints on inventory holding strategies.

Shah [7] produced one of the earliest sector-specific analyses of pharmaceutical supply chain challenges, identifying the tension between the industry's historically high margins—which historically discouraged rigorous cost management—and the emerging competitive pressures of generics markets, which demand operational efficiency. Shah's observation that pharmaceutical companies have been slower to adopt SCM best practices than industries such as automotive or retail remains partially valid, though the pace of digital adoption has accelerated substantially since that study was published.

Kache and Seuring [8] examined the intersection of big data analytics and supply chain management, arguing that the growing availability of high-frequency transactional data from point-of-sale systems, electronic health records, and IoT devices creates opportunities for demand forecasting accuracy that were previously unattainable. Their framework is particularly relevant to pharmaceutical SCM, where prescription volume data constitutes a rich and underutilized source of demand signal.

Ivanov and Dolgui [9] introduced the concept of supply chain viability, distinguishing between resilience (the capacity to absorb and recover from disruption) and survivability (the capacity to maintain essential functions under severe and prolonged disruption). This distinction is operationally meaningful in pharmaceuticals: a supply chain that can recover from a logistics delay (resilience) may nonetheless be incapable of maintaining medicine availability during a prolonged API shortage (survivability), as demonstrated during the COVID-19 pandemic.

Kumar and Ganguly [10] conducted one of the more recent empirical analyses of SCM practices in Indian pharmaceutical companies, identifying supplier relationship management, information sharing quality, and transportation network optimization as the three strongest predictors of overall supply chain performance. Their finding that information sharing quality has a stronger effect on performance than physical logistics efficiency is consistent with the broader supply chain literature and suggests that investments in digital integration platforms may generate higher returns than equivalent investments in physical infrastructure.

Govindan et al. [11] analyzed supply chain network design under uncertainty, demonstrating that multi-echelon inventory optimization models can substantially reduce both safety stock requirements and stockout probabilities when demand uncertainty is explicitly incorporated into the planning framework. This work provides theoretical justification for the deployment of AI-driven demand sensing tools in pharmaceutical supply chains.

3. METHODOLOGY

3.1 Research Design

This study adopts a mixed-methods descriptive-analytical design. Qualitative data were gathered through semi-structured interviews with supply chain managers, procurement officers, quality assurance personnel, and warehouse supervisors at both study organizations. Quantitative data were obtained through structured questionnaires administered to a purposively selected sample of 87 respondents across manufacturing, logistics, and distribution functions. Secondary data sources included audited annual reports, company investor presentations, regulatory submission documents publicly available via the CDSCO portal, and peer-reviewed academic literature identified through a systematic search of PubMed, Scopus, and Google Scholar.

3.2 Data Collection Instruments

The primary questionnaire comprised 42 items organized into six dimensions: (i) supplier integration and qualification, (ii) manufacturing and quality systems, (iii) inventory management practices, (iv) transportation and logistics management, (v) information technology adoption, and (vi) regulatory compliance and risk management. Items were measured on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree). Content validity was established through expert review by three academic SCM specialists and two industry practitioners prior to deployment.

3.3 Analytical Approach

Data were analyzed using IBM SPSS Statistics version 26. Descriptive statistics (means, standard deviations, and frequency distributions) were computed for all scale items. Pearson correlation analysis was employed to assess bivariate associations between SCM dimension scores and self-reported performance outcomes. Linear regression was used to identify the relative predictive weight of each SCM dimension on a composite operational performance index. Chi-square tests evaluated the association between technology adoption categories and performance quartile classification.

For the comparative organizational analysis, financial ratios (inventory turnover, order fulfillment rate, perfect order percentage) and operational ratios (stockout frequency, expiry write-off percentage) were computed from secondary data and compared between the two study organizations and against published industry benchmarks.

3.4 Ethical Considerations

All survey participants provided informed consent prior to participation. Organizational data were anonymized in individual-level reporting. The study was conducted in accordance with the ethical guidelines of the Indian Council of Medical Research (ICMR) for observational research in healthcare organizations.

4. STRUCTURE OF THE PHARMACEUTICAL SUPPLY CHAIN

A pharmaceutical supply chain constitutes a complex, multi-echelon network that extends from the procurement of chemical precursors to the point of patient dispensing. Each node in this network performs distinct but interdependent functions, and the failure of any single node has cascading consequences for downstream medicine availability. Table 1 summarizes the principal components of this network and their functional roles.

Table 1. Structural Components of the Pharmaceutical Supply Chain and Their Functional Roles

No.	Component	Functional Description
1	Raw Material Suppliers	Procure Active Pharmaceutical Ingredients (APIs), excipients, and packaging components under cGMP-compliant standards
2	Pharmaceutical Manufacturers	Transform raw materials into finished dosage forms (tablets, injectables, biologics) through validated manufacturing and QC processes
3	Warehousing	Maintain controlled-environment storage, batch segregation, cold chain integrity, and regulatory-compliant inventory records
4	Distributors/Wholesalers	Provide bulk-to-unit disaggregation, last-mile logistics, and cold chain management between manufacturers and dispensing points
5	Retail Pharmacies	Dispense prescription and OTC products, conduct patient counseling, and generate real-time demand signals for upstream planning
6	Regulatory Bodies	Enforce GMP, GDP, serialization, and pharmacovigilance mandates (e.g., CDSCO/DCGI in India; FDA in the USA)

Source: Adapted and expanded from Shah (2004) and Chopra & Meindl (2019)

What distinguishes the pharmaceutical supply chain from those of most other industries is the regulatory overlay that governs virtually every transaction within the network. Good Manufacturing Practice (GMP), Good Distribution Practice (GDP), Good Storage Practice (GSP), and Good Pharmacovigilance Practice (GVP) collectively create a compliance architecture that raises the operational complexity and cost of pharmaceutical logistics relative to comparator sectors. Non-compliance at any tier of the supply chain can

trigger product recalls, market withdrawals, or regulatory action against multiple entities within the same supply network.

5. COMPARATIVE ANALYSIS: HARMAN FINOCHEM AND SUN PHARMA

5.1 Harman Finochem Limited: API Manufacturing SCM

Harman Finochem Limited, headquartered in Aurangabad, Maharashtra, was established in 1984 under the leadership of Mr. Bhupinder Singh Manhas. The company operates manufacturing facilities in Aurangabad and Vapi with a combined fermentation and synthesis capacity of 350,000 liters, producing over 45 Active Pharmaceutical Ingredients across therapeutic categories including cardiovascular agents (e.g., fenofibrate), anticonvulsants (e.g., divalproex sodium), antivirals (e.g., acyclovir), antimicrobials, and specialty chemicals. Harman Finochem's products are exported to more than 75 countries and are classified under WHO's Model List of Essential Medicines for more than 10 product categories.

From an SCM perspective, Harman Finochem's supply chain is organized around a two-tier structure. At the upstream tier, the company sources chemical precursors and intermediates from qualified domestic and international suppliers, applying cGMP-compliant supplier qualification procedures that include site audits, certificate of analysis review, and periodic re-qualification. The company's proposed expansion facility at Nandgaon Peth MIDC in Amravati, with a projected production capacity of 6,241 MT per month across 33 products, will require a commensurate expansion of procurement and inbound logistics infrastructure.

At the downstream tier, the company's customers are predominantly pharmaceutical formulation manufacturers rather than end consumers or retail channels. This business-to-business orientation simplifies certain aspects of demand management—because customers place bulk, scheduled orders—but introduces concentration risk when major customers represent a disproportionate share of revenue. The study found that Harman Finochem employs SAP-based ERP for production planning and procurement management, but that integration between the ERP system and third-party logistics providers remained incomplete at the time of data collection, creating periodic blind spots in shipment visibility.

5.2 Sun Pharmaceutical Industries: Integrated Global SCM

Sun Pharmaceutical Industries presents a substantially more complex SCM architecture, commensurate with its status as the world's fourth-largest specialty generic pharmaceutical company by market capitalization. Operating in more than 100 countries and manufacturing across 43 production facilities on multiple continents, Sun Pharma's supply chain must simultaneously manage the procurement of thousands of raw material SKUs, the production planning of hundreds of formulations across multiple dosage forms, and the distribution of finished goods through heterogeneous national distribution systems governed by country-specific regulations.

The company deploys a hybrid push-pull supply chain strategy. Manufacturing and primary distribution to regional warehouses and distribution centers are governed by push logic, with production schedules derived from statistical demand forecasts generated by the SAP Integrated Business Planning (IBP) platform. Replenishment from regional warehouses to wholesale distributors, pharmacies, and hospitals operates on pull logic, triggered by downstream order signals. This architectural choice—consistent with the

decoupling point concept articulated in the broader SCM literature [5]—allows Sun Pharma to achieve manufacturing scale economies while maintaining customer responsiveness at the dispensing point.

The company has made substantial investments in cold chain logistics infrastructure to support its specialty and biologic product portfolio. Temperature-controlled storage at distribution centers, refrigerated transport vehicles, and IoT-enabled temperature data loggers deployed throughout the distribution network collectively ensure that cold chain integrity can be documented and verified for regulatory purposes. Barcode and RFID scanning at warehouse receiving and dispatch points enable real-time inventory accuracy rates that far exceed what was achievable under the manual systems they replaced.

6. COST DISTRIBUTION IN PHARMACEUTICAL SCM

Understanding the cost architecture of pharmaceutical supply chains is essential for identifying high-impact intervention points. Based on analysis of publicly available financial data from study organizations and benchmarking against published industry models [5, 12], pharmaceutical SCM costs can be categorized as shown in Table 2.

Table 2. Cost Distribution Across Pharmaceutical Supply Chain Functions

SCM Cost Category	Share (%)	Key Cost Drivers
Manufacturing	25	Production labor, equipment depreciation, QC testing, GMP compliance overhead
Procurement	20	API sourcing, supplier qualification, import duties, raw material price volatility
Inventory Management	20	Holding costs, obsolescence/expiry write-offs, cold storage, FIFO compliance
Distribution	20	Wholesaler margins, last-mile logistics, serialization compliance (DSCSA/EU FMD)
Transportation	15	Freight rates, cold chain transport, fuel surcharges, route optimization costs

Source: Derived from Chopra & Meindl (2019) and primary organizational data

Manufacturing costs dominate the total SCM cost structure at 25%, reflecting the capital intensity of pharmaceutical production, the labor requirements of manual processes that cannot yet be fully automated, and the overhead of GMP compliance infrastructure (environmental monitoring, validated cleaning systems, documentation management). Procurement, inventory management, and distribution each account for 20% of total supply chain costs—a notably equal distribution that underscores the need for balanced optimization rather than selective focus on a single cost category. Transportation, at 15%, has historically been underinvested in pharmaceutical SCM relative to its operational significance, particularly given the growing prevalence of temperature-sensitive products that require specialized logistics infrastructure.

7. IDENTIFIED CHALLENGES IN PHARMACEUTICAL SCM

7.1 Departmental Siloization and Integration Deficits

Across both study organizations, one of the most consistently reported barriers to supply chain performance was the tendency of different functional departments to optimize for local metrics rather than system-wide outcomes. Procurement departments focused on unit cost minimization accepted longer lead times and minimum order quantities that destabilized production schedules. Production departments that prioritized capacity utilization generated inventory positions that logistics departments struggled to distribute within product expiry windows. This observation aligns with the theoretical framework of Lambert and Cooper [13], who characterized supply chain integration as a multi-dimensional construct requiring not only information system linkage but also aligned incentive structures and cross-functional decision-making authority.

7.2 Inadequate New Product Development (NPD) Integration

In both organizations, supply chain functions were routinely engaged late in the new product development process—typically at the point of commercial scale-up rather than during early formulation or clinical development. This delayed engagement meant that supply chain constraints (API lead times, packaging material availability, cold chain requirements) were often discovered after development commitments had been made, necessitating costly redesigns or market launch delays. The literature consistently identifies early supply chain involvement in NPD as a significant predictor of time-to-market performance in pharmaceutical organizations [10, 14].

7.3 Counterfeit Medicine Risk and Serialization Compliance

The Indian pharmaceutical market is estimated to contain a significant proportion of substandard and falsified (SF) medicines, with WHO estimates suggesting that SF medicines account for a meaningful share of antimalarial and antibiotic products circulating in low- and middle-income country markets. Both study organizations faced compliance obligations under India's emerging drug serialization framework, which requires unique identifier codes at the primary packaging level for specified product categories. Implementation challenges included integrating serialization data into legacy ERP systems, training staff in barcode application procedures, and establishing data exchange protocols with downstream supply chain partners who maintained different information systems.

7.4 Cold Chain Vulnerability

The growing proportion of pharmaceutical products requiring temperature-controlled storage and distribution—including monoclonal antibodies, vaccines, insulin, and ophthalmological preparations—has elevated cold chain management from a niche logistics concern to a mainstream supply chain priority. Temperature excursions during transportation remain a significant cause of product quality failures, and documentation of cold chain compliance has become a routine element of regulatory inspection. Both study organizations reported cold chain as an area requiring ongoing investment and attention, with particular challenges at the last-mile distribution stage where refrigerated transport capacity is most constrained.

8. TECHNOLOGICAL ENABLERS OF PHARMACEUTICAL SCM PERFORMANCE

The past decade has witnessed an accelerating deployment of digital technologies across pharmaceutical supply chains. Table 3 summarizes the principal technologies and their applications within pharmaceutical SCM.

Table 3. Digital Technologies Deployed in Pharmaceutical SCM and Their Operational Benefits

Technology	Primary SCM Application	Pharmaceutical Benefit
AI / ML	Demand sensing, supply disruption prediction	Reduces stockouts and overstocking by up to 30%
Blockchain	Serialized track-and-trace, e-pedigree	Counterfeit drug detection and regulatory compliance
IoT Sensors	Real-time temperature and humidity monitoring	Cold chain integrity for vaccines, biologics, insulin
ERP (SAP IBP)	Integrated planning across procurement, production, logistics	Single source of truth for global inventory visibility
RFID	Automated warehouse receiving, picking, and dispatch	Error reduction in dispensing and order fulfillment
Digital Twins	Supply chain scenario simulation and stress testing	Identifies bottlenecks before operational disruption
Cloud Platforms	Multi-party data sharing with CMOs and distributors	Accelerates partner onboarding and data reconciliation

Source: Compiled from Kache & Seuring (2017), Ivanov & Dolgui (2020), and primary organizational interviews

Artificial intelligence and machine learning applications in demand forecasting represent perhaps the most broadly applicable technology investment for pharmaceutical SCM. Unlike traditional statistical forecasting methods that rely on historical shipment data as a proxy for demand, modern AI demand-sensing platforms can incorporate prescription volume data from electronic health records, epidemiological surveillance data, and social media health indicators to generate demand forecasts that are more accurate and temporally precise. Early adopters of AI-based demand sensing in pharmaceutical SCM have reported meaningful reductions in both stockout rates and inventory holding costs, reflecting the dual benefit of improved service levels and reduced working capital requirements.

Blockchain-based track-and-trace systems have moved from proof-of-concept to production deployment among major pharmaceutical distributors in the United States and Europe, driven in part by the compliance requirements of the Drug Supply Chain Security Act (DSCSA). The immutable, distributed ledger structure of blockchain technology makes it technically difficult to insert counterfeit products into a tracked supply chain, and provides regulatory authorities with an auditable record of every custody transfer event. While the operational costs of blockchain deployment remain non-trivial, particularly for smaller distribution entities, the technology's potential contribution to patient safety justifies serious evaluation.

9. PROPOSED SCM IMPROVEMENT FRAMEWORK

Based on the analytical findings of this study, the following multi-dimensional framework is proposed for improving pharmaceutical supply chain performance. The framework is organized across five strategic dimensions:

Dimension 1: Supply Chain Integration

1. Establish cross-functional supply chain governance committees with representation from procurement, production, quality assurance, logistics, and commercial functions.
2. Align departmental performance metrics with system-wide SCM outcomes (e.g., perfect order rate, total supply chain cost) rather than functional efficiency metrics alone.
3. Integrate supply chain professionals into NPD project teams from the clinical development stage to ensure commercial-scale supply considerations inform development decisions.

Dimension 2: Inventory Optimization

4. Deploy multi-echelon inventory optimization (MEIO) models that account for demand variability, lead time uncertainty, and shelf life constraints simultaneously.
5. Implement FIFO (First In, First Out) discipline rigorously across all warehousing stages, supported by ERP-enforced stock rotation algorithms.
6. Establish differentiated safety stock policies by product criticality category (essential medicines, emergency medicines, elective medicines) to avoid uniform over-stocking.

Dimension 3: Digital Infrastructure

7. Prioritize ERP integration with third-party logistics providers to eliminate shipment visibility gaps and enable proactive exception management.
8. Deploy IoT temperature monitoring across cold chain nodes, with automated alert protocols and regulatory-grade data archiving.
9. Evaluate blockchain-based serialization for export markets subject to DSCSA or EU Falsified Medicines Directive (FMD) compliance requirements.

Dimension 4: Supplier Development and Risk Management

10. Diversify API sourcing across at least two qualified suppliers per critical ingredient to reduce single-source dependency risk.
11. Conduct structured supply chain risk assessments annually, incorporating geopolitical risk, supplier financial health, and regulatory compliance history.
12. Establish vendor-managed inventory (VMI) arrangements with strategic suppliers to reduce procurement lead times and improve supply predictability.

Dimension 5: Human Capital and Organizational Learning

13. Develop structured SCM training curricula for pharmacy and operations staff, integrating GDP compliance, cold chain management, and digital tool competencies.
14. Establish supply chain performance dashboards accessible to operational staff to enable data-driven decision-making at all levels of the organization.

10. RESULTS AND DISCUSSION

Correlation analysis revealed statistically significant positive associations between technology adoption scores and composite supply chain performance ($r = 0.67$, $p < 0.001$), consistent with the hypothesis that digital investment drives measurable operational improvement. Notably, the information sharing quality dimension showed the strongest independent predictor of performance outcomes in regression analysis ($\beta = 0.41$, $p < 0.001$), replicating the finding of Kumar and Ganguly [10] and reinforcing the primacy of data integration over physical logistics investment.

Comparative analysis between the two study organizations revealed that Sun Pharma's more mature digital infrastructure and cross-functional governance structures correlated with superior performance on inventory turnover (8.2x vs. 5.4x annualized), perfect order rate (94.3% vs. 87.1%), and expiry write-off percentage (0.8% vs. 2.3% of inventory value). These differences persisted after controlling for product portfolio complexity and distribution network size, suggesting that organizational and technological factors rather than structural factors account for the performance gap.

The identification of departmental siloization as a major operational barrier is consistent across both organizations and echoes findings from the broader SCM literature [13, 14]. Resolving this challenge requires not only technological intervention but organizational redesign: the reallocation of decision rights, the realignment of incentive structures, and the cultivation of a supply chain-centric organizational culture that prioritizes end-to-end performance over functional efficiency. These changes are inherently slower and more difficult to achieve than technology deployments, and represent the more fundamental long-term challenge for pharmaceutical SCM improvement in the Indian context.

The study also found evidence that the cost distribution model presented in Table 2 overstates the proportional importance of manufacturing costs when compared to the total cost of supply chain failures. When stockout events, expiry write-offs, and regulatory non-compliance penalties are incorporated into the cost analysis, the effective cost of suboptimal inventory management and distribution practices substantially exceeds the nominal 20% each allocated to these categories in the standard model. This finding has implications for investment prioritization: organizations that optimize manufacturing costs while tolerating poor inventory and distribution practices are likely misallocating their improvement resources.

11. CONCLUSION

This study demonstrates that supply chain management represents a critical determinant of pharmaceutical industry performance, with measurable consequences for medicine availability, patient safety, regulatory compliance, and organizational financial results. Comparative analysis of Harman Finochem and Sun Pharmaceutical Industries reveals a performance spectrum within the Indian pharmaceutical sector that is attributable not to inherent industry constraints but to differences in organizational integration, digital infrastructure, and supply chain governance maturity.

The cost architecture of pharmaceutical SCM, with manufacturing representing the largest single cost category at 25% and procurement, inventory, and distribution each contributing 20%, suggests multiple high-impact intervention points. However, regression analysis indicates that information sharing quality—an

organizational and technological capability rather than a physical infrastructure investment—is the strongest predictor of overall supply chain performance. This finding counsels against the common industry instinct to address performance deficiencies primarily through logistics infrastructure investment.

The proposed five-dimension improvement framework offers a structured roadmap for pharmaceutical organizations seeking to advance their supply chain capabilities. Successful implementation requires simultaneous progress across integration, technology, inventory practice, supplier management, and human capital dimensions—a recognition that supply chain excellence is a systemic property that cannot be achieved through isolated improvements in any single area.

Future research should examine the longitudinal effects of specific technology investments on pharmaceutical supply chain performance, with particular attention to the cost-benefit profile of blockchain serialization in the Indian regulatory context, and the applicability of AI demand-sensing tools to the demand patterns characteristic of essential medicines in resource-constrained health systems.

REFERENCES

1. Oliver K. Interview: A conversation with the father of supply chain management. Supply Chain Management Review. 2003.
2. Handfield RB, Nichols EL. Introduction to Supply Chain Management. Prentice Hall; 2015.
3. Agarwal N, Karwa M. Pharmaceutical Regulations in India. Pharmaceutical Medicine and Translational Clinical Research. 2018;215-231.
4. Akhter S. India wants to become a very significant player in the global supply chain of pharmaceuticals. ET Health World. 2019.
5. Chopra S, Meindl P. Supply Chain Management: Strategy, Planning, and Operation. 7th ed. Pearson Education; 2019.
6. Christopher M. Logistics and Supply Chain Management. 5th ed. Pearson; 2016.
7. Shah N. Pharmaceutical supply chains: key issues and strategies for optimisation. Comput Chem Eng. 2004;28(6-7):929-941.
8. Kache F, Seuring S. Challenges and opportunities of digital information at the intersection of big data analytics and supply chain management. Int J Oper Prod Manag. 2017;37(1):10-36.
9. Ivanov D, Dolgui A. Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. Int J Prod Res. 2020;58(10):2904-2915.
10. Kumar S, Ganguly KK. Supply chain management in the pharmaceutical industry. Int J Supply Chain Manag. 2019;8(2):215-223.
11. Govindan K, Fattahi M, Keyvanshokooh E. Supply chain network design under uncertainty. Eur J Oper Res. 2017;263(1):108-141.
12. Simchi-Levi D, Kaminsky P, Simchi-Levi E. Designing and Managing the Supply Chain. 4th ed. McGraw-Hill; 2020.

13. Lambert DM, Cooper MC. Issues in supply chain management. Ind Mark Manag. 2000;29(1):65-83.
14. Lee HL, Billington C. The evolution of supply chain management models and practice. Interfaces. 1995;25(5):42-63.
15. Mentzer JT, DeWitt W, Keebler JS, et al. Defining supply chain management. J Bus Logist. 2001;22(2):1-25.
16. Agarwal A, Shankar R. Analyzing alternatives for improvement in supply chain performance. Int J Prod Perform Manag. 2005;54(1):68-82.
17. Gunasekaran A, Patel C, Tirtiroglu E. Performance measures and metrics in a supply chain environment. Int J Oper Prod Manag. 2001;21(1-2):71-87.
18. Carvalho H, Duarte S, Machado VC. Lean, agile, resilient and green supply chain management. Int J Prod Res. 2011;49(12):3433-3451.
19. Sun Pharmaceutical Industries Ltd. Annual Report 2023-24. Mumbai: Sun Pharma; 2024.
20. Harman Finochem Ltd. Environmental Impact Assessment Report: Proposed API Manufacturing Facility, Nandgaon Peth, Amravati. Maharashtra: MIDC; 2023.