Educational Administration: Theory and Practice
2024, 30(2), 2203-2213
ISSN: 2148-2403
https://kuey.net/
Research Article

Role of Artificial Intelligence and Blockchain in Strengthening Supply Chain Operations in the Pharmaceutical Sector in India

Dr Mohd Iqbal Khan[1], Dr Rais Ahmad Itoo[2], Dr Syed Irfan Shafi[3]

[1]Assistant Professor, Department of Management Studies, Islamic University of Science and Technology, Pulwama, Kashmir. Email:ikhan7073@gmail.com
[2]Assistant Professor, Department of Management Studies, Islamic University of Science and Technology, Pulwama, Kashmir. Email: rais.ahmad.itoo@gmail.com
[3]Assistant Professor, Department of Management Studies, Islamic University of Science and Technology, Pulwama, Kashmir. Email: drsyedirfanshafi@gmail.com

Citation: Khan M. I., et al. (2024). Role of Artificial Intelligence and Blockchain in Strengthening Supply Chain Operations in the Pharmaceutical Sector in India, *Educational Administration: Theory and Practice*, 30(2) 2203-2213
Doi: 10.53555/kuey.v30i2.11214

ARTICLE INFO	ABSTRACT
Received: *10-06-2023* Revised: *25-11-2023* Accepted: *11-02-2024* Published: *28-02-2024* Corresponding Author: Dr Syed Irfan Shafi *drsyedirfanshafi@gmail.com*	Digital technologies like Artificial Intelligence (AI) and Blockchain are changing the way global supply chains work very quickly. They are opening up new ways to make operations more open, efficient, and resilient. In India's pharmaceutical industry, where fake drugs, broken logistics, and regulatory problems are still problems, these technologies show a lot of promise. This study examines the influence of AI and Blockchain on enhancing pharmaceutical supply chain operations in India, emphasizing their effects on transparency, traceability, efficiency, and consumer trust. Utilizing the Technology–Organization–Environment (TOE) framework and the Resource-Based View (RBV), the study formulates and empirically evaluates a conceptual model that incorporates AI capabilities, Blockchain transparency, and the degree of technological integration as principal factors influencing supply chain performance. Primary data were gathered from 272 respondents, encompassing pharmaceutical manufacturers, distributors, and logistics providers throughout India. Structural Equation Modeling (SEM) through AMOS 28.0 was used to look at the data. The results show that using AI makes the supply chain much more efficient by using predictive analytics and process optimization. Blockchain technology, on the other hand, makes things more transparent by making sure that data is accurate, traceable, and can be found. The results also show that the level of technological integration partially affects the link between AI–Blockchain adoption and performance outcomes, making their positive effects on consumer trust and operational excellence even stronger. The research enhances theoretical frameworks by integrating the TOE and RBV models and advancing digital supply chain literature through empirical validation of AI–Blockchain convergence in a developing economic context. From a management point of view, it gives a plan for strategic investment, regulatory alignment, improving digital literacy, and building a collaborative ecosystem to make the pharmaceutical supply chain more open and strong. The study finds that combining AI and Blockchain in a way that works together is a key factor in India's pharmaceutical sector's digital transformation, compliance with regulations, and long-term competitiveness. **Keywords:** Artificial Intelligence, Blockchain, Supply Chain Efficiency, Pharmaceutical Industry, Technological Integration, Transparency, India are some of the words that come to mind.

Introduction

The Pharmaceutical Industry creates an integral element in India's Health Care System, ensuring that individuals have access to life-saving medicines in a timely manner. The complexity of and importance of Pharmaceutical Supply Chains emphasizes the need to maintain the integrity, transparency and efficiency of these Supply Chains to protect the Public's Health and support Economic Stability (Shah & Singh, 2021). Supply Chain integrity guarantees the authenticity, safety and efficacy of medicinal products from the time of manufacturing to final delivery. The ongoing challenges that exist throughout the globe, especially in Developing Countries like India, include counterfeit drugs, weak traceability and other operational inefficiencies (WHO, 2022). WHO indicates that in Low and Middle Income Countries, approximately 10% of all Medical Products are Counterfeit or Substandard and therefore pose serious risks to Patient Safety and undermine Trust in the Health Care System. As one of the Largest Producers and Exporters of Generic Medicines in the World, India is particularly Vulnerable to the Problems that accompany enormous Distribution Networks, Fragmented Regulation and Logistical Bottlenecks (Kumar et al., 2020). Counterfeit Drugs pose a Risk on the Health of Individuals, damage the Reputation of the Industry, cause losses and add to the Cost of Drugs through a lack of Traceability and inefficient Distribution systems (Raut et al., 2021). The Current Situation clearly demonstrates the Urgent Need for Technological Innovations to provide improved Visibility, Traceability and Accountability in the Pharmaceutical Supply Chain. The emerging technologies of Artificial Intelligence (AI) and Blockchain have the potential to transform the way these problems are addressed in the future. For example, AI predictive analytics can enhance demand forecasting; automate inventory decision making; and enhance logistics optimization on a real-time basis (Dwivedi et al., 2021). Blockchain enables businesses to maintain an external, unchangeable and decentralized ledger which increases data accuracy and product traceability throughout multiple supply chain nodes (Saberi et al., 2019). Combined, these two technologies can significantly enhance the ability of the Pharmaceutical Supply Chain to remain free from counterfeit products, enhance supply chain efficiency and improve the level of patient trust in both the Pharmaceutical Supply Chain and the Pharmaceutical Supply Chain Products they use (Kshetri, 2021). However, empirical research into the combined role of these technologies in India is limited; most studies that have been published have considered AI or Blockchain technology individually (Ghosh & Bhattacharya, 2022). In this regard, the purpose of this research study is to bridge the identified gap by determining the impact of AI Predictive Analytics, Blockchain Transparency, Automation and Smart Logistics, and Data Security and Traceability, mediated by Technological Integration Level, on Supply Chain Efficiency, Operational Transparency, Counterfeit Reduction, and Customer Trust. The intention of this study is to evaluate the extent of adoption, examine the extent to which businesses have experienced improved performance as a result of the implementation of AI and Blockchain technologies, the extent to which counterfeit products have been mitigated, cost versus trust issues, and ultimately propose recommendations for how AI – Blockchain technology can be effectively adopted and integrated into the Pharmaceutical Ecosystem in India.

Literature Review

The literature shows that Artificial Intelligence and blockchain are transforming pharmaceutical supply chains by improving efficiency, transparency, and product authenticity. AI enhances forecasting, inventory management, and logistics performance, while blockchain ensures secure, traceable, and tamper-proof records that strengthen regulatory compliance and operational transparency. When combined, these technologies significantly reduce counterfeit drugs through real-time detection and immutable tracking, which in turn increases consumer trust in pharmaceutical products. Importantly, studies highlight that effective technological integration maximises these benefits by enabling seamless coordination between AI's predictive capabilities and blockchain's traceability functions.

Adopting AI and making the supply chain work better

Artificial Intelligence (AI) has become a pivotal enabler of digital transformation in supply chain management, offering advanced capabilities in automation, prediction, and decision optimization. AI tools like machine learning, predictive analytics, and robotic process automation help businesses better predict demand, keep their inventory at the right level, and make their logistics operations run more smoothly (Dwivedi et al., 2021; Min, 2022). In the pharmaceutical sector, AI supports real-time monitoring of cold-chain logistics, enhances delivery scheduling, and reduces manual errors in production and distribution processes. Recent research indicates that the incorporation of AI enhances operational efficiency, reduces costs, and elevates service quality throughout global supply chains (Wamba & Queiroz, 2023; Eyo-Udo, 2023). In India, AI is still new, but it has a lot of potential to improve pharmaceutical logistics, especially by fixing problems with distribution and regulatory paperwork (Raut et al., 2021). By facilitating predictive analytics, anomaly detection, and automated decision-making, AI ensures that supply chain operations become more agile and data-driven. Based on these empirical findings, the following hypothesis is posited:

H1: The use of artificial intelligence in the pharmaceutical industry has a big and positive effect on the efficiency of the supply chain.

Blockchain Technology and Operational Transparency

Blockchain technology has been widely recognized for its ability to enhance data transparency, traceability, and trust across supply chain networks. As a decentralized ledger system, blockchain records every transaction in an immutable and verifiable manner, thereby preventing data manipulation and reducing information asymmetry (Saberi et al., 2019). Blockchain enables drug serialization, shipment authentication, and real-time verification of production and distribution activities within pharmaceutical supply chains (Kshetri, 2021; Sun, 2023). Empirical evidence suggests that blockchain-enabled supply chains improve auditability and reduce compliance costs, creating a transparent and accountable system for all stakeholders (Vu, 2023). Furthermore, transparency achieved through blockchain fosters stronger inter-organizational collaboration and regulatory oversight (Tandon et al., 2022). In the Indian context, where counterfeit drugs and fragmented distribution are persistent issues, blockchain offers a viable solution to enhance operational integrity and public safety. Accordingly, the study hypothesizes:

H2: Blockchain implementation positively influences operational transparency within the pharmaceutical supply chain.

Combined Role of AI and Blockchain in Counterfeit Drug Reduction

The integration of AI and blockchain represents a technological convergence that enhances both predictive capability and data integrity in supply chain management. AI's predictive analytics and anomaly detection capabilities can identify irregularities in production or shipment data, while blockchain ensures that such data remain immutable and traceable across all nodes (Chaudhuri et al., 2022). This dual mechanism is particularly vital for combating counterfeit drugs, which continue to undermine pharmaceutical quality and patient safety in emerging markets. Empirical studies have demonstrated that blockchain's traceability systems, combined with AI-based detection algorithms, substantially reduce the risk of counterfeit infiltration by providing real-time authentication of products (Gaynor, 2023). These technologies together create a "trust architecture" where the authenticity of every pharmaceutical unit can be validated at each stage of the supply chain (Kamble et al., 2021). Hence, the following hypothesis is formulated:

H3: The integration of AI and Blockchain technologies significantly contributes to the reduction of counterfeit drugs in the pharmaceutical supply chain.

Counterfeit Drug Reduction and Consumer Trust

Counterfeit drug proliferation poses a major threat to patient safety, brand reputation, and regulatory compliance. Reducing counterfeit incidents not only improves product authenticity but also strengthens consumer and patient trust in pharmaceutical brands (WHO, 2022). Prior research has found that supply chain transparency and traceability facilitated through digital technologies positively influence consumer confidence, as customers are assured of product origin and quality (Upadhyay et al., 2023; Tandon et al., 2022). In markets like India, where the risk of counterfeit medicines remains high, firms that implement digital verification mechanisms can differentiate themselves by demonstrating higher reliability and ethical responsibility (Shah & Singh, 2021). Trust, in this sense, becomes both a behavioral outcome and a strategic asset, resulting from consistent transparency and authenticity. Therefore, the study posits:

H4: Reduction in counterfeit drugs positively influences consumer trust in pharmaceutical products.

Mediating Role of Technological Integration in Efficiency and Trust

While AI and blockchain independently contribute to improved performance, their full potential is realized only when they are effectively integrated within a firm's operational and information systems. Technological Integration Level refers to the degree of interoperability, data coordination, and cross-functional alignment achieved through the use of these digital tools (Kumar et al., 2022). Integration enables seamless communication between systems, ensuring that AI's predictive insights are directly linked with blockchain's traceability mechanisms for synchronized decision-making. Prior studies confirm that integration acts as a strategic mediator that amplifies the performance benefits of technological adoption (Chaudhuri et al., 2022). Firms with mature integration systems report higher efficiency, transparency, and trust compared to those implementing technologies in isolation (Wamba & Queiroz, 2023). Therefore, the hypothesis is stated as:

H5: Technological Integration mediates and enhances the positive effects of AI and Blockchain adoption on supply chain efficiency and consumer trust.

Research Methodology

Research Design

This study adopts a quantitative, explanatory, and cross-sectional research design to empirically examine the role of Artificial Intelligence (AI) and Blockchain in strengthening supply chain operations within India's pharmaceutical sector. The study framework is built on the Technology Organisation Environment (TOE) and Resource Based View (RBV) paradigms, which together explain how technological capabilities, organizational readiness, and integration influence supply chain performance outcomes (Barney, 1991; Tornatzky & Fleischer, 1990). The research design enables assessment of both direct and mediated effects, particularly how the

Technological Integration Level mediates the relationship between AI–Blockchain adoption and key operational outcomes such as efficiency, transparency, counterfeit drug reduction, and consumer trust.

Population and Sampling

The target population for this study comprised pharmaceutical manufacturers, distributors, logistics service providers, and regulatory-affiliated organizations operating across India. These entities represent critical nodes in the pharmaceutical supply chain, encompassing production, packaging, warehousing, quality control, and distribution functions. The study focused on firms that have either adopted or are in the process of adopting Artificial Intelligence (AI) and Blockchain technologies to enhance their supply chain operations. The sample was drawn from leading pharmaceutical firms registered with the Pharmaceuticals Export Promotion Council of India (Pharmexcil) and included both multinational and domestic companies. Prominent participants in the study included Sun Pharmaceutical Industries Ltd., Dr. Reddy's Laboratories, Cipla Ltd., Lupin Ltd., Aurobindo Pharma, Torrent Pharmaceuticals, Glenmark Pharmaceuticals, Zydus Lifesciences, Alkem Laboratories, Mankind Pharma, and selected mid-tier logistics and distribution partners such as TCI Pharma Logistics and Safexpress Healthcare Division. These firms were chosen because of their strategic role in national and global pharmaceutical supply chains, as well as their early engagement with digital transformation initiatives.

A purposive sampling technique was employed to ensure that respondents possessed relevant expertise and practical experience in technology-enabled supply chain management. The sampling unit consisted of professionals directly involved in digital and operational decision-making, including supply chain managers, IT specialists, operations heads, regulatory compliance officers, and quality assurance executives, who could provide informed insights into the adoption and integration of AI and Blockchain technologies. A total of 300 questionnaires were distributed electronically and in person across the identified firms. Consistent with guidelines for Structural Equation Modeling (SEM), which recommend at least ten observations per indicator variable (Hair et al., 2022), this sample size was considered statistically adequate for model testing. After rigorous screening for completeness, reliability, and response consistency, 272 valid responses were retained for final analysis. These 272 responses represent individual respondents, not entire organizations meaning that each participant provided their own professional perspective based on their firm's adoption status and operational experiences. The distribution of respondents by organizational type was as follows: 48% from manufacturing firms, 27% from distribution and logistics service providers, 15% from contract manufacturers and packaging units, and 10% from regulatory or quality compliance offices. This composition ensured comprehensive coverage of all major components of the pharmaceutical supply chain, enhancing the representativeness and generalizability of the study findings.

Instrument Design

Data for the study were collected using a structured questionnaire developed from previously validated measurement scales, carefully adapted to suit the context of India's pharmaceutical supply chain. The instrument was divided into five major sections to comprehensively capture the variables under investigation. The first section included demographic information such as firm size, years of operation, type of organization, and the role of the respondent within the supply chain function. The second section focused on AI Predictive Analytics, which measured the extent to which firms employed predictive algorithms, demand forecasting models, and automation tools to enhance decision-making and operational efficiency (Dwivedi et al., 2021). The third section dealt with Blockchain Transparency, incorporating items that assessed data immutability, traceability, and transaction visibility across the supply chain network (Saberi et al., 2019). The fourth section combined indicators related to Automation and Smart Logistics and Data Security and Traceability, capturing the degree of logistics optimization, integration of Internet of Things (IoT) devices, and the robustness of information security mechanisms implemented by firms (Kamble et al., 2020). The fifth section measured the Technological Integration Level the mediating variable—and included dependent variables such as supply chain efficiency, operational transparency, counterfeit drug reduction, and consumer or patient trust (Chaudhuri et al., 2022). All constructs were measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) to capture respondents' perceptions accurately. Prior to large-scale administration, a pilot test was conducted with 30 respondents drawn from similar professional backgrounds to assess the clarity, reliability, and face validity of the questionnaire items. Based on feedback, minor adjustments were made to improve phrasing and ensure contextual relevance. The results of the pilot test indicated that the Cronbach's alpha values for all constructs exceeded the recommended threshold of 0.70 (Nunnally, 1978), confirming the internal consistency and reliability of the instrument.

Data Collection Procedure

Data for the present study were gathered through online and offline modes. Respondents were approached via professional networks, industry associations, and LinkedIn groups related to pharmaceutical logistics and operations. Participation was voluntary, and confidentiality of responses was assured.

Data Analysis

The purpose of the analysis is to empirically validate the proposed conceptual framework examining how Artificial Intelligence (AI) and Blockchain technologies strengthen supply chain operations in the Indian pharmaceutical sector. The data collected from 272 respondents were analyzed using SPSS 28.0 and AMOS 28.0, applying a combination of descriptive statistics, reliability and validity testing, correlation analysis, and Structural Equation Modeling (SEM) to assess both direct and mediated effects.

Descriptive Statistics

Descriptive statistics summarize respondents' perceptions of AI and Blockchain adoption within the pharmaceutical supply chain.

Table 1: Descriptive Statistics

Construct	Mean	S.D.
AI Predictive Analytics	3.94	0.71
Blockchain Transparency	3.76	0.74
Automation & Smart Logistics	3.88	0.69
Data Security & Traceability	4.01	0.65
Supply Chain Efficiency	3.92	0.72
Consumer Trust	3.85	0.70

Respondents perceive a progressive integration of AI and Blockchain technologies in their operations. Higher mean scores for data security and efficiency indicate that these technologies are increasingly contributing to reliability and operational performance in the pharmaceutical sector.

Reliability and Validity

The study's data were gathered through a structured questionnaire formulated from previously validated scales and tailored to the Indian pharmaceutical supply chain context. We used Cronbach's alpha and Composite Reliability (CR) to check the reliability of each construct. We used Average Variance Extracted (AVE) and the Fornell-Larcker criterion to check Convergent Validity and Discriminant Validity, respectively. The Cronbach's alpha values for all constructs were higher than 0.70, which means that the internal consistency was good (Nunnally, 1978).

Table 2: Reliability and Validity of Constructs

Construct	No. of Items	Cronbach's Alpha (α)	Composite Reliability (CR)	Average Variance Extracted (AVE)
AI Predictive Analytics	6	0.89	0.91	0.67
Blockchain Transparency	5	0.87	0.90	0.63
Automation & Smart Logistics	5	0.88	0.92	0.66
Data Security & Traceability	4	0.86	0.90	0.65
Technological Integration Level	5	0.90	0.93	0.69
Supply Chain Efficiency	4	0.88	0.91	0.68
Operational Transparency	4	0.89	0.92	0.70
Counterfeit Drug Reduction	3	0.87	0.90	0.64
Consumer Trust	5	0.91	0.94	0.71

All constructs demonstrated Cronbach's alpha values above 0.70 and Composite Reliability (CR) values above 0.80, confirming strong internal consistency and reliability. The Average Variance Extracted (AVE) values were all greater than the threshold of 0.50, establishing convergent validity (Hair et al., 2022). Additionally, the Fornell-Larcker criterion verified discriminant validity, as the square root of AVE for each construct exceeded its correlations with other constructs. Hence, the measurement instrument was deemed statistically robust for subsequent Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM).

Correlation Analysis

To assess the strength and direction of relationships among the primary constructs, Pearson's correlation coefficient (r) was calculated. We chose correlation analysis because it gives us a statistical way to see how closely two continuous variables are related (Hair et al., 2022). This method is especially good when the data meets parametric assumptions like linearity, interval scale measurement, and an approximate normal distribution. Additionally, correlation coefficients were examined to confirm that the association strength among independent variables did not exceed the threshold of $r = 0.85$, thereby eliminating significant multicollinearity concerns that could compromise SEM estimations (Kline, 2023). Table 3 shows the correlation matrix, which shows the pairwise relationships between constructs.

Table 3: Correlation Matrix

Constructs	AI	Blockchain	Integration	Efficiency	Transparency	Trust
AI Predictive Analytics	1	0.63**	0.59**	0.66**	0.58**	0.52**
Blockchain Transparency		1	0.62**	0.61**	0.65**	0.57**
Technological Integration			1	0.67**	0.64**	0.60**
Supply Chain Efficiency				1	0.69**	0.63**
Operational Transparency					1	0.66**
Consumer Trust						1

Note: p < 0.01 (two-tailed)

The findings indicate robust, positive, and statistically significant correlations among all constructs, with all coefficients reaching significance at the 0.01 level (two-tailed). This finding suggests that the implementation of AI and Blockchain technologies is significantly linked to enhancements in technological integration, supply chain efficiency, and stakeholder trust. The correlation between AI and supply chain efficiency ($r = 0.66$, $p < 0.01$) shows that using predictive analytics and automation more often makes operations run more smoothly and quickly. The strong link between Blockchain and operational transparency ($r = 0.65$, $p < 0.01$) shows how important Blockchain is for making sure that all parts of the supply chain can be traced and trusted. The correlation between Technological Integration and Efficiency ($r = 0.67$) and between Integration and Transparency ($r = 0.64$) further confirms that the effective alignment of AI and Blockchain capabilities enhances end-to-end visibility and data interoperability within pharmaceutical supply chains. Furthermore, Consumer Trust shows moderate to strong correlations with both Efficiency ($r = 0.63$) and Transparency ($r = 0.66$). This means that customers' trust in pharmaceutical products goes up when technology is used to make things run more smoothly. These results align with previous research in the discipline. Culot et al. (2023) and Eyo-Udo (2023) discovered that AI-enabled logistics analytics markedly enhances responsiveness and reliability within global supply chains. The positive correlation patterns observed here empirically reinforce these arguments, underscoring the synergistic relationship between AI's predictive capabilities and Blockchain's transparency features (Trivedi, 2023). In conclusion, the correlation analysis confirms that the constructs being examined are conceptually related while remaining distinct, thereby establishing a statistically robust foundation for advancing to Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM). The substantial positive correlations among technological adoption, integration, and performance outcomes provide initial validation for the study's hypotheses that AI and Blockchain technologies collaboratively improve supply chain efficiency, transparency, and trust in India's pharmaceutical sector.

Confirmatory Factor Analysis (CFA)

We used Confirmatory Factor Analysis (CFA) to check the validity, reliability, and dimensional structure of the measurement model we made for this study. This study utilized Confirmatory Factor Analysis (CFA) to validate the relationships between the latent constructs AI Predictive Analytics, Blockchain Transparency, Automation & Smart Logistics, Data Security & Traceability, Technological Integration, Supply Chain Efficiency, Operational Transparency, Counterfeit Drug Reduction, and Consumer Trust and their respective observed indicators.

Table 4: Confirmatory Factor Analysis (CFA) Results

Constructs / Dimensions	No. of Items	Standardized Factor Loadings (Range)	Composite Reliability (CR)	Average Variance Extracted (AVE)
AI Predictive Analytics	5	0.79 – 0.87	0.91	0.67
Blockchain Transparency	4	0.77 – 0.85	0.90	0.63
Automation & Smart Logistics	4	0.80 – 0.88	0.92	0.66
Data Security & Traceability	4	0.79 – 0.87	0.90	0.65
Technological Integration Level (Mediator)	5	0.82 – 0.88	0.93	0.69
Supply Chain Efficiency	4	0.80 – 0.86	0.91	0.68
Operational Transparency	4	0.83 – 0.88	0.92	0.70
Counterfeit Drug Reduction	3	0.78 – 0.85	0.90	0.64
Consumer/Patient Trust	5	0.83 – 0.89	0.94	0.71

The Confirmatory Factor Analysis (CFA) results show that the measurement model is very reliable, valid, and consistent with theory. All constructs exhibited standardized factor loadings significantly exceeding the minimum acceptable threshold of 0.70, with values ranging from 0.78 to 0.89. This confirms that the observed variables substantially loaded onto their respective latent constructs (Hair et al., 2022). This shows that each indicator played an important role in measuring its corresponding construct, which kept the measurement framework consistent. The Composite Reliability (CR) values for all constructs were between 0.90 and 0.94, which is higher than the suggested minimum of 0.70 (Fornell & Larcker, 1981). This shows that the latent constructs are measured reliably across their indicators and that the internal consistency is high. The Average Variance Extracted (AVE) values ranged from 0.63 to 0.71, which is higher than the acceptable level of 0.50. This shows that the items are in agreement with each other, which is what convergent validity means. The constructs with the highest reliability and convergent validity were Consumer/Patient Trust (CR = 0.94, AVE = 0.71) and Technological Integration Level (CR = 0.93, AVE = 0.69). This means that these variables are well-captured and theoretically strong in the model. In the same way, AI Predictive Analytics (CR = 0.91, AVE = 0.67) and Blockchain Transparency (CR = 0.90, AVE = 0.63) were also very reliable. This shows that these technological factors are statistically different and well-measured dimensions that help the overall model fit.

Measurement model

The model fit very well overall, with all of the indices meeting or exceeding the recommended levels. The χ^2/df ratio of 2.16 shows that the model fits the data well, and the CFI (0.948) and TLI (0.936) show that the model fits even better. The RMSEA (0.062) and SRMR (0.054) values are both in the acceptable range. This means that the model accurately represents the data that was observed and that there is little residual error. The Goodness-of-Fit Index (GFI) of 0.925 confirms that the model can explain things even more. All of these results together show that the proposed measurement model fits the real-world data well.

Table 5: Model Fit Indices (Measurement Model)

Fit Index	Recommended Value	Obtained Value
χ^2/df	< 3.0	2.16
Comparative Fit Index (CFI)	> 0.90	0.948
Tucker–Lewis Index (TLI)	> 0.90	0.936
Root Mean Square Error of Approximation (RMSEA)	< 0.08	0.062
Standardized Root Mean Square Residual (SRMR)	< 0.08	0.054

Structural Equation Modeling (SEM)

Before testing the proposed structural relationships among constructs, correlation analysis was performed as an initial statistical procedure to assess the strength, direction, and significance of the associations among the latent variables in the model. Correlation analysis is a crucial diagnostic procedure in multivariate modeling, as it offers preliminary evidence of interrelationships among constructs, thereby validating or challenging the theoretical assumptions that underpin the proposed framework (Hair et al., 2022). The correlation analysis showed that all of the constructs were moderately to strongly positively correlated, with coefficients between 0.52 and 0.69, all of which were significant at the 0.01 level (two-tailed). These results indicate that the constructs are positively correlated, as theoretically anticipated, but not to a degree that would elicit concerns regarding multicollinearity. The strong links between AI Predictive Analytics and Supply Chain Efficiency ($r = 0.66$, $p < 0.01$) and between Blockchain Transparency and Operational Transparency ($r = 0.65$, $p < 0.01$) show that both technologies work together to make the pharmaceutical supply chain work better. Likewise, the correlation between Technological Integration and Consumer Trust ($r = 0.60$, $p < 0.01$) underscores the mediating role of integration maturity in transforming technological adoption into stakeholder confidence. At this point, it was both methodologically and theoretically sound to do a correlation analysis.

Table 6: Structural Model Path Coefficients

Hypothesis	Relationship	Path Coefficient (β)	t-value	p-value
H1	AI → Supply Chain Efficiency	0.38	5.12	0.000
H2	Blockchain → Operational Transparency	0.41	5.46	0.000
H3	AI & Blockchain → Counterfeit Drug Reduction	0.36	4.92	0.000
H4	Counterfeit Reduction → Consumer Trust	0.33	4.25	0.000
H5	Technological Integration → Efficiency & Trust (Mediation)	0.29	4.05	0.001

All hypothesized relationships were statistically significant ($p < 0.05$). AI adoption significantly improves supply chain efficiency ($\beta = 0.38$), while Blockchain enhances operational transparency ($\beta = 0.41$). The Technological Integration Level partially mediates the relationship between technological adoption and performance outcomes, confirming that firms with higher integration maturity achieve superior efficiency and trust levels.

Mediation Analysis

Mediation testing was conducted using bootstrapping (5,000 resamples) to assess the indirect effect of technological integration.

Table 7: Mediation Effects (Bootstrapping Results)

Relationship	Direct Effect	Indirect Effect	Total Effect	Mediation Type
AI → Efficiency (via Integration)	0.38	0.12	0.50	Partial
Blockchain → Transparency (via Integration)	0.41	0.10	0.51	Partial

The study shows that Technology Integration partially mediates the effect of Technology Adoption to Supply Chain Performance as seen by the mediation analysis results. The indirect effects of AI on Efficiency through Technology Integration were $\beta = 0.12$ ($p < 0.01$), while the direct effects were still $\beta = 0.38$ ($p < 0.001$). Likewise, Blockchain's indirect effects on Transparency through Technology Integration were at $\beta = 0.10$ ($p < 0.01$) with a direct effect of $\beta = 0.41$ ($p < 0.001$). Thus, while the Technology Integration enhances the direct effect that each Technology has, it does not eliminate the need for organizations to have inter-departmental collaboration and interoperability. The use of AI's Predictive Analytics and Blockchain's Immutable Ledgers among organizations looked at within this study are shown to improve Traceability tremendously ($\beta = 0.65$, $p < 0.001$), decrease Counterfeit Drug Risk ($\beta = 0.36$, $p < 0.001$), and improve Regulatory Compliance ($\beta = 0.33$, $p < 0.001$). Integration Maturity was determined to be a key factor for Performance, whereby organizations with highly integrated capabilities achieved more Efficiency ($\beta = 0.67$, $p < 0.001$), more Transparency ($\beta = 0.64$, $p < 0.001$), and greater Consumer Trust ($\beta = 0.60$, $p < 0.001$). Overall, this study supports the overall finding that the combination of AI and Blockchain Technologies improves Efficiency, Transparency, and Reliability within the Indian Pharmaceutical Supply Chain and corroborates the Global Evidence for Digital Transformational Strategic Impact (Dwivedi et al., 2021; Saberi et al., 2019; Wamba & Queiroz, 2023).

Conclusion

This present research concludes that collaborating on AI and Blockchain technologies will enhance efficiency, transparency and trust in India's pharmaceutical supply chain. Evidence from this study supports the synergies provided through innovative integration will generate more value than the use of either technology alone. Through predictive analytics powered by artificial intelligence support forecasting better, automates inventory management decisions, and provides optimal resource allocation which gives organizations the agility to react quickly to changing markets; while blockchain provides immutability of data, secure transactions, and end-to-end traceability that create traceable digital elements that remove information asymmetries and build accountability. The research also shows that the amount of integration maturity significantly improves all of the aforementioned benefits resulting from AI and Blockchain technology ($\beta = 0.29$, $p < 0.001$), but that the partial mediation relationship shows that that while integration provides benefits it does not remove the direct benefit of AI and Blockchain technologies. This reinforces the need for organizational digital alignment, process redesign, and knowledge sharing to maximize the potential of technology. In summary, AI and Blockchain are both best used as complementary technologies to provide improved efficiency in supply chain operations ($\beta = 0.38$), enhance the operational transparency of organizations ($\beta = 0.41$), reduce counterfeit products ($\beta = 0.36$) and increase confidence in the product ($\beta = 0.33$, all $p <0.001$) which have been strategically important to strengthen compliance, bolster public health initiatives, and demonstrate that stakeholders can have confidence in the organization that produced the product. Results from this study also demonstrate the importance of collaborative support by providing supportive regulatory frameworks for the development of scaled integrated digital solutions that align technological innovation with societal welfare and safety in health care.

Theoretical and Managerial Implications

This research theoretically contributes to the literature on Supply Chain Management (SCM) and Digital Transformation (DT). The research programme provides the theoretical integration of the Resource-Based View (RBV) and Technology-Organisation-Environment (TOE) Frameworks to understand how Artificial Intelligence (AI) and Blockchain are generating strategic value for firms. The TOE view is focused on organisations' readiness to adopt technologies and external pressures on firms to adopt DLs. The RBV view provides the means to understand how a firm's unique environments create unique advantages. The key take away from this research, then, is that AI and Blockchain will only become strategic assets when they are successfully integrated into a firm's operational processes and shaped by the firm's external conditions, particularly in highly regulated markets such as Pharmaceuticals in India. This research also presents a rare empirical perspective on the interactions between AI and Blockchain in terms of their synergistic effects in Emerging Markets. While previous studies explored the effects of each on their respective areas of influence, this research demonstrates how AI and Blockchain are complementary to one another; AI is predictive and Blockchain is secure, thus providing a new theoretical foundation for Technological Synergy. Finally, this research introduced Technological Integration Level as a mediating construct to support the development of a Digital Resilience capability; this provides a new way to understand how Digital Capability can be built from integration capability. In sum, this research provides a unifying perspective to support how companies leverage their Digital Technologies in a coordinated fashion to create Intelligent, Transparent, and Competitive Supply Chains.

The results of this study show that pharmaceutical companies need to invest in creating AI–Blockchain platforms that incorporate real-time data sharing, predictive capabilities, and secure traceability between companies and their suppliers. Furthermore, pharmaceutical companies' managers should ensure they integrate their AI forecasting tools with their Blockchain tracing technology in order to create cross-functional synergy between logistics, quality control, and regulatory compliance. As can be concluded from this study, the companies who had the highest levels of integration maturity through effective organizational redesigns and development of digital skill sets experience significantly increased levels of efficiency ($\beta = 0.38$), transparency ($\beta = 0.41$), and customer trust ($\beta = 0.33$, all $p < 0.001$). For policymakers such as the CDSCO and MoHFW, establishing digital governance frameworks (including digital ledger mandates, serialization regulations, and interoperability standards) is critical in establishing the institutionalization of supply chain transparency. Furthermore, regulatory sandboxes and pilot programs can be used to help create safe environments for new product testing with the added benefit of allowing companies to accelerate the adoption of new markets. In addition, collaborative partnerships among the technology provider community, the manufacturers, and their logistics partners will significantly increase both the standardization of data across industries and the level of visibility within a company's operations as well as enhance the ability to implement cybersecurity measures to achieve scalable and sustainable digital transformations.

Limitations and Future Research Directions

The study provides significant empirical and theoretical insights; however, several limitations necessitate attention. First, the research employed a cross-sectional design, which limits causal inference. Subsequent research should utilize longitudinal methodologies to monitor the progression of AI-Blockchain integration and its enduring impact on supply chain performance. Second, the data were predominantly gathered via self-reported survey responses, potentially leading to perceptual bias. Subsequent research may integrate survey data with objective performance metrics or case-based evidence to augment validity. Third, the study only looked at India's pharmaceutical sector. This is very relevant, but it may not be possible to apply the findings to other industries. Future comparative studies across various sectors (e.g., food, healthcare equipment, or agriculture) and emerging economies may yield cross-contextual insights into challenges of digital adoption and regulatory disparities. Lastly, adding other new technologies to the current model, like the Internet of Things (IoT), digital twins, edge computing, or 5G-enabled analytics, could help us better understand how technological ecosystems change supply chain operations as a whole. These kinds of studies would help both academic theory and business practice move forward in the age of smart, open, and long-lasting supply chains.

References

1. Ahuja, V., & Thatcher, S. M. B. (2021). Artificial intelligence in operations management: A review and research agenda. *Journal of Operations Management*, 67(1), 45–62.
2. Alkahtani, M., & Nawaz, N. (2022). Blockchain for pharmaceutical supply chain traceability: Opportunities and challenges. *Technological Forecasting and Social Change*, 180, 121664.
3. Arora, S., & Kapoor, R. (2023). Digital transformation in India's healthcare supply chains: Exploring the role of AI and blockchain. *International Journal of Production Economics*, 256, 108726.
4. Bag, S., Wood, L. C., & Xu, L. D. (2020). Artificial intelligence in supply chain management: A review and bibliometric analysis. *Technological Forecasting and Social Change*, 162, 120351.
5. Bala, M., & Singh, V. (2022). Blockchain adoption in the Indian pharmaceutical industry: An empirical study. *Journal of Enterprise Information Management*, 35(7), 1981–2002.
6. Bharadwaj, A. S. (2000). A resource-based perspective on information technology capability and firm performance. *MIS Quarterly*, 24(1), 169–196.
7. Bhardwaj, A., & Singh, S. (2022). AI-enabled traceability for counterfeit drug detection: A case from India. *Decision Analytics Journal*, 5, 100090.
8. Bianchini, A., & Michalk, W. (2021). Blockchain in healthcare logistics: A systematic review. *Computers & Industrial Engineering*, 159, 107497.
9. Boehmke, B. C., & Hazen, B. T. (2017). The future of supply chain management: Artificial intelligence and predictive analytics. *Supply Chain Management Review*, 21(4), 34–41.
10. Byrne, B. M. (2016). *Structural equation modeling with AMOS: Basic concepts, applications, and programming* (3rd ed.). Routledge.Field, A. (2020). *Discovering statistics using IBM SPSS statistics* (5th ed.). Sage Publications.
11. Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)* (3rd ed.). Sage Publications. Kline, R. B. (2023). *Principles and practice of structural equation modeling* (5th ed.). Guilford Press.
12. Chopra, S., & Meindl, P. (2019). *Supply Chain Management: Strategy, Planning, and Operation* (7th ed.). Pearson Education.
13. Choudhury, N., & Dey, P. (2023). Enhancing pharmaceutical supply chain resilience through AI–Blockchain convergence. *Operations and Supply Chain Management Journal*, 16(2), 112–128.
14. Culot, G., Nassimbeni, G., & Orzes, G. (2023). Artificial intelligence and digital transformation in global supply chains: A systematic review and future research agenda. *International Journal of Production Economics, 266*, 109220.
15. Deloitte. (2022). *Blockchain in Life Sciences: Transforming the pharmaceutical supply chain*. Deloitte Insights.
16. Dwivedi, Y. K., Hughes, L., & Rana, N. P. (2021). Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, 57, 101994.
17. Eyo-Udo, E. (2023). Artificial intelligence for resilient supply chains: Evidence from emerging economies. *Frontiers in Artificial Intelligence, 7*(4), 1477044.
18. Flynn, B. B., Huo, B., & Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of Operations Management*, 28(1), 58–71.
19. Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, 18(1), 39–50.
20. Gaur, J., & Tiwari, S. (2022). Integrating blockchain with AI for sustainable pharmaceutical logistics. *Sustainable Production and Consumption*, 33, 652–665.
21. Ghosh, S., & Saha, S. (2023). Counterfeit drugs and blockchain technology: A new era of pharmaceutical transparency. *Journal of Business Research*, 161, 113836.
22. Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)* (3rd ed.). Sage Publications.
23. Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science, 43*(1), 115–135.
24. Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling, 6*(1), 1–55.
25. Iqbal, M. A., & Ahmad, M. (2023). Technological integration and supply chain efficiency: Evidence from Indian manufacturing. *Journal of Business Logistics*, 44(1), 91–109.
26. Jhawar, N., & Dutta, A. (2022). Digital transparency and consumer trust in the Indian pharma supply chain. *Journal of Supply Chain Management*, 58(3), 76–98.
27. Kapoor, K., & Dwivedi, Y. K. (2021). Enabling digital transformation through Blockchain and AI: Empirical evidence from Indian organizations. *Government Information Quarterly*, 38(4), 101668.

28. Khan, M., & Mishra, A. (2023). Blockchain-based drug traceability in India: Policy, adoption, and implementation challenges. *Health Policy and Technology*, 12(1).
29. Kline, R. B. (2023). *Principles and practice of structural equation modeling* (5th ed.). Guilford Press.
30. Kshetri, N. (2021). Blockchain and AI's role in global supply chain security. *Computer*, 54(5), 108–113.
31. Kumar, R., & Singh, M. (2020). Impact of blockchain technology on supply chain performance: An empirical study. *International Journal of Logistics Research and Applications*, 23(3), 214–232.
32. Lee, H. L. (2020). The triple-A supply chain revisited: Agility, adaptability, and alignment. *International Journal of Production Economics*, 227, 107672.
33. Liu, Y., & Chen, M. (2022). AI and blockchain for pharmaceutical integrity: A systematic review. *Journal of Cleaner Production*, 370, 133356.
34. Mehta, P., & Bansal, S. (2023). Evaluating the readiness for blockchain adoption in India's pharmaceutical supply chain. *Technology in Society*, 74, 102322.
35. Mikalef, P., & Krogstie, J. (2020). Investigating the effects of big data analytics capabilities on firm performance: The mediating role of dynamic capabilities. *Information & Management*, 57(2), 103–169.
36. Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*, 40(3), 879–891.
37. Rai, A., & Tang, X. (2021). Digital supply networks and innovation diffusion in the pharmaceutical sector. *MIS Quarterly Executive*, 20(3), 165–187.
38. Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, 57(7), 2117–2135.
39. Sahay, B. S., & Mohan, R. (2022). The digital supply chain transformation in India: A focus on pharmaceuticals. *Journal of Operations and Strategic Management*, 5(1), 45–60.
40. Sharma, V., & Gupta, R. (2022). Examining the mediating role of technological integration in digital supply chains. *Information Systems Frontiers*, 24(6), 1693–1710.
41. Singh, A., & Tandon, R. (2021). Leveraging AI for demand forecasting in pharmaceutical logistics. *Computers & Industrial Engineering*, 158, 107398.
42. Sun, Y. (2023). Blockchain for pharmaceutical traceability: A comprehensive empirical analysis. *Journal of Business Research, 173*, 114206.
43. Trivedi, R. (2023). Blockchain-based solutions for trust and transparency in supply chain management. *Asia Pacific Journal of Business Administration, 17*(1), 1–18.
44. Vu, T. (2023). Leveraging blockchain to strengthen traceability and regulatory compliance in healthcare logistics. *Technological Forecasting and Social Change, 199*, 122682.
45. World Health Organization (WHO). (2022). *Counterfeit medicines: Facts and figures*. WHO Publications.