



SUPPLY CHAIN STRATEGIES OF PHARMACEUTICAL COMPANIES: AN OPTIMIZATION AND INTEGRATION OF ARTIFICIAL INTELLIGENCE

DR. MICHAEL L. DE LA CRUZ

Institute of Graduate and Professional Studies
Lyceum Northwestern University, Dagupan City, Philippines
mldelacruz@rtu.edu.ph

ABSTRACT

This study aims to explore the integration of Artificial Intelligence (AI) into pharmaceutical companies' supply chain strategies and its impact on key performance indicators (KPIs) such as cost efficiency, inventory turnover, delivery fulfilment, and supply chain robustness. The principal objective is to assess how AI adoption enhances operational performance while addressing challenges in implementation. A mixed-methods approach was employed, combining quantitative data gathered from surveys with qualitative insights to analyze AI's role in optimizing supply chains. Statistical tools were used to evaluate the relationship between AI integration and various performance metrics. The results indicate that AI adoption significantly improves cost efficiency, inventory management, and on-time delivery, demonstrating a positive correlation between AI use and enhanced supply chain performance. However, challenges related to data quality, governance, and ethical considerations persist, particularly in delivery fulfilment and supply chain resilience. It concludes that while AI offers substantial benefits in streamlining supply chain operations, pharmaceutical companies must address these challenges to fully leverage AI's potential. Stronger integration into organizational culture, leadership support, and enhanced data governance practices are recommended to optimize AI-driven improvements in supply chain performance, ultimately contributing to a more efficient and resilient pharmaceutical sector.

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Keywords: *Supply Chain Strategies, Artificial Intelligence, Key Performance Indicators, Market Dynamics, Technological Advancement, Environmental Sustainability*

INTRODUCTION

The pharmaceutical industry, as a critical pillar of global healthcare, faces immense pressure to ensure the availability, affordability, and accessibility of life-saving medications. However, the industry is increasingly challenged by the complexities of its global supply chains, characterized by stringent regulatory requirements, fluctuating demand, and product perishability. Traditional supply chain management strategies often struggle to cope with these complexities, resulting in inefficiencies that directly impact product availability, cost management, and overall operational performance.

As the pharmaceutical industry grows in both scope and in scope and scale, adapting supply chain strategies becomes critical in meeting shifting market demands. However, many pharmaceutical companies find their conventional approaches outdated and insufficient for addressing modern challenges. This problem is further compounded by the pressure to adopt advanced technologies such as artificial intelligence (AI), which promises enhanced operational efficiency and risk mitigation. Despite the potential benefits of AI integration, pharmaceutical companies face significant hurdles, including organizational readiness, data governance, and the need for compliance with stringent industry regulations.

This research addresses the pressing need to optimize supply chain strategies in the pharmaceutical sector by integrating AI technologies to enhance key performance indicators (KPIs). The study explores how AI can transform traditional supply chain practices by improving demand forecasting, inventory management, and regulatory compliance. By doing

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so, it seeks to offer actionable insights into overcoming the barriers of AI adoption, contributing to sustainable growth and competitiveness in the pharmaceutical sector.

REVIEW OF RELEVANT LITERATURE

Supply Chain Strategies in the Pharmaceutical Industry

Supply chain management is crucial in determining the success of pharmaceutical companies as it impacts cost efficiency, product availability, and operational performance. According to Moosivand et al. (2019), improving pharmaceutical supply chains through collaborative relationships with suppliers and investment in new technologies can help maintain a competitive advantage. Supply chain strategies need to be adaptable and responsive to fluctuations in demand, regulatory changes, and the global distribution of products. Moreover, Wang et al. (2020) emphasize that integrating diverse stakeholders and systems within supply chains can alleviate uncertainty and enhance agility, and allows companies to be able to respond more effectively to disruptions.

AI and Digital Technology in Supply Chain Management

Integrating Artificial Intelligence into supply chains is increasingly viewed as a transformative strategy for improving operational efficiency. Alomar et al. (2022) suggest that AI can optimize supply chain performance by enhancing accuracy, productivity, and safety across various operational areas, including logistics, marketing, and manufacturing. AI algorithms offer advanced analytics and predictive modeling capabilities, allowing pharmaceutical companies to improve demand forecasting, reduce stockouts, and streamline inventory management. Similarly, Wu Guo et al. (2023) emphasize the potential of Artificial intelligence to transform pharmaceutical supply chains by automating critical processes and enabling real-time monitoring of regulatory compliance.

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Kumar et al. (2023) emphasize the importance of digital technologies, especially the Internet of Things (IoT), in improving transparency and traceability across the pharmaceutical supply chain. IoT devices enable real-time monitoring of inventory levels, temperature conditions, and product movement, thereby boosting supply chain efficiency and minimizing the risk of counterfeiting. These advancements not only enhance operational performance but also support patient safety and ensure regulatory compliance.

Challenges in AI Adoption

Despite the clear benefits, the adoption of AI within pharmaceutical supply chains is not without challenges. Companies face hurdles related to data governance, regulatory compliance, and organizational readiness for digital transformation. Fernando et al. (2020) identify several critical strategic concerns in the pharmaceutical sector, such as information technology integration, performance evaluation metrics, and reverse supply chain management, all of which must be addressed to ensure the successful implementation of AI-driven solutions. Additionally, Shashi et al. (2023) note that digital technology integration can enhance sustainability and profitability in pharmaceutical supply chains but caution that companies must overcome technological adoption and resource allocation limitations.

Implications for the Pharmaceutical Industry

The literature highlights that pharmaceutical companies must continuously refine their supply chain strategies to meet evolving market demands and regulatory pressures. By integrating AI and digital technologies, companies can optimize supply chain processes, enhance transparency, and improve operational efficiency. However, adopting these technologies requires careful planning and a solid commitment to overcoming organizational and regulatory challenges. The insights from this literature review provide a foundation for exploring best practices in AI integration and its potential to revolutionize pharmaceutical supply chain management.

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Theoretical Framework

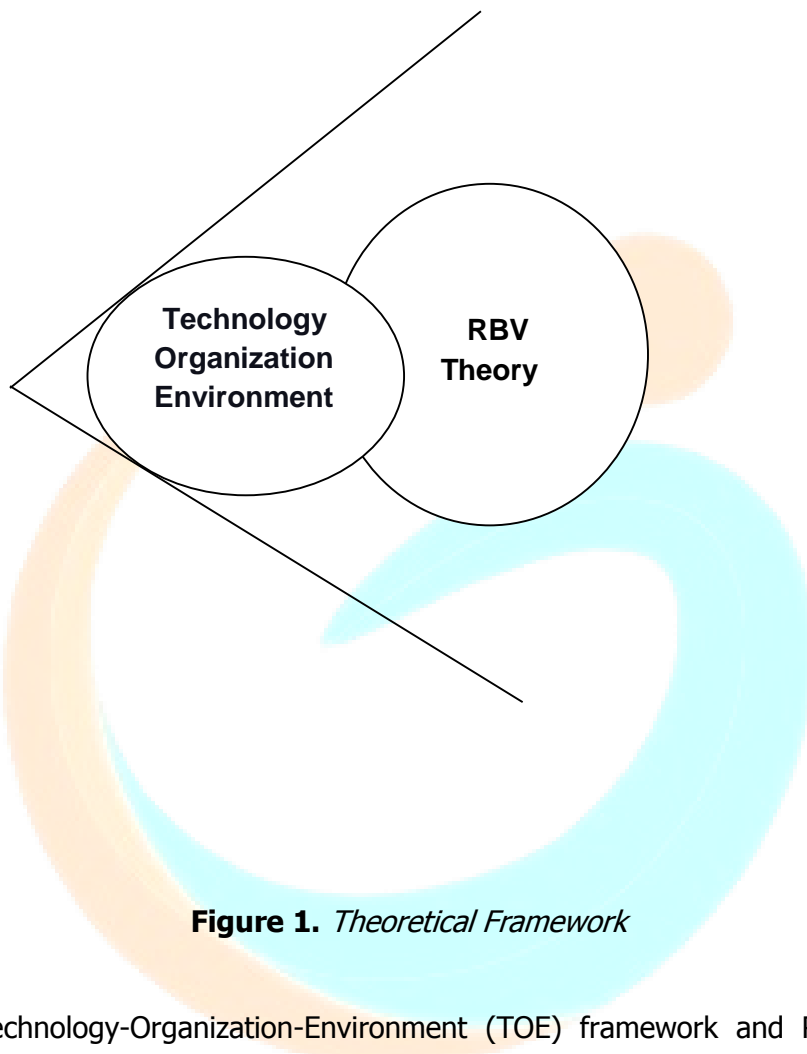


Figure 1. *Theoretical Framework*

The Technology-Organization-Environment (TOE) framework and Resource-Based View (RBV) theory provide complementary lenses for analyzing the adoption of AI technologies within pharmaceutical supply chains. The TOE framework explores the interaction of technological, organizational, and environmental factors that shape technology adoption, offering insights into internal aspects such as AI readiness and organizational capabilities, as well as external influences like regulatory conditions and industry trends. Studies by Hoti (2015) and Abdul Rahman et al. (2023) underscore the transformative impact

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of supply chain technologies in improving efficiency and competitiveness, particularly for smaller enterprises. Similarly, da Silva et al. (2019) highlight the significance of technological and organizational factors in implementing drug traceability systems.

The RBV theory complements this by focusing on how internal resources and capabilities, such as data analytics and supply chain infrastructure, create competitive advantages. According to Chahal et al. (2020), adaptability, seamless supply chain integration, and organizational prowess are key to operational efficiency and market success. Combining TOE and RBV enables a holistic understanding of AI adoption in pharmaceutical supply chains, focusing on both external influences and the strategic use of internal resources. This integrated approach offers a robust framework for optimizing supply chain performance and sustaining competitive advantages in a complex, regulated industry.

Conceptual Framework

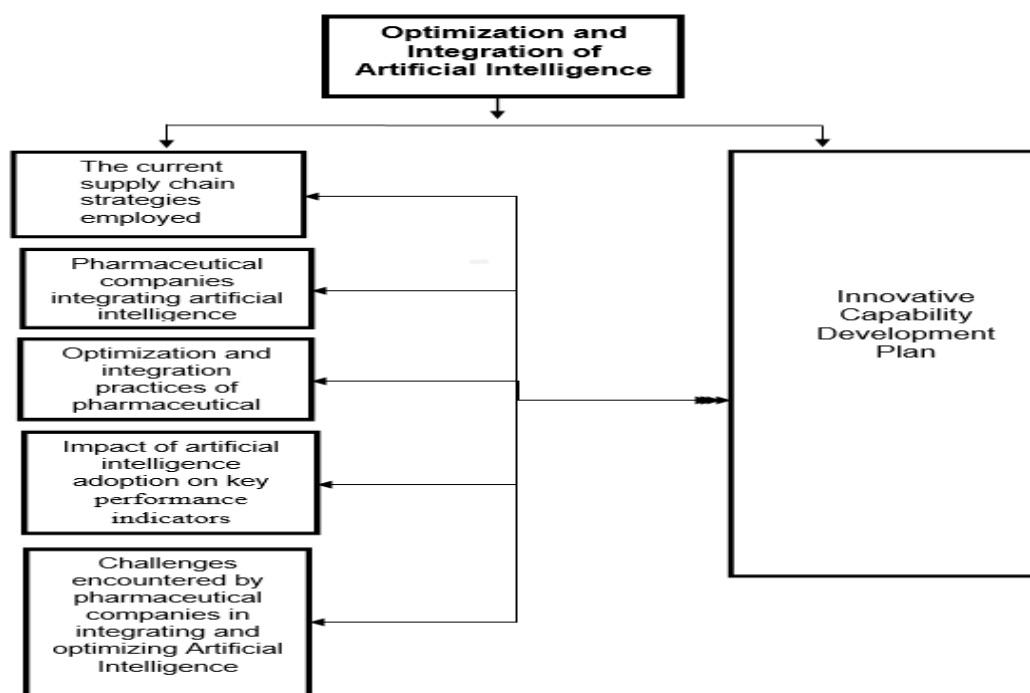


Figure 2. Research Paradigm

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A mixed-methods approach is well-suited for this study, blending both quantitative and qualitative techniques to gain a thorough understanding of pharmaceutical companies' supply chain strategies and the effects of AI integration on critical performance metrics. Quantitative methods, such as surveys and statistical analysis, will be used to collect and evaluate data on supply chain performance indicators, AI adoption rates, and metrics like cost efficiency and inventory turnover. This combination of methods allows for triangulation, which strengthens the study's validity and reliability while offering a deeper insight into how technology, organizational factors, and external influences affect supply chain performance in the pharmaceutical sector.

Purpose of the Research

This study aimed to assess the supply chain strategies of pharmaceutical companies, using optimization and integration of Artificial Intelligence to enhance Key Performance Indicators. Specifically, this study sought to answer the following sub-problems:

1. What do pharmaceutical companies employ the current supply chain strategies in terms of:
 - 1.1 Adoption Rate of AI Technologies,
 - 1.2 Cost efficiency,
 - 1.3 Inventory Turnover, and
 - 1.4 On-time Delivery Performance?
2. To what extent are pharmaceutical companies integrating artificial intelligence (AI) technologies into their supply chain operations:
 - 2.1 Organizational culture,
 - 2.2 Leadership Support,
 - 2.3 Data Quality and Governance, and
 - 2.4 Regulatory Compliance?

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3. Is there a significant relationship between pharmaceutical companies' current supply chain strategies and the integration of artificial intelligence (AI) technologies into their supply chain operations?
4. What are the optimization and integration practices of pharmaceutical companies in mitigating potential risk in terms of:
 - 4.1 Market dynamics,
 - 4.2 Technological Advancement,
 - 4.3 Supply Chain Resilience,
 - 4.4 Customer Satisfaction, and
 - 4.5 Environmental Sustainability?
5. What is the impact of artificial intelligence adoption on key performance indicators of pharmaceutical companies in terms of:
 - 5.1 Delivery fulfillment,
 - 5.2 Quality System Effectiveness,
 - 5.3 Change Control and Compliance, and
 - 5.4 Supply Chain Robustness?
6. What challenges are pharmaceutical companies encountering in integrating and optimizing Artificial Intelligence towards the key performance indicators (KPIs)?
7. Based on the study's findings, what innovative capability development plan could be proposed to enhance and address the challenges identified on the key performance indicators (KPIs)?

Hypotheses

H1: There is a significant relationship between pharmaceutical companies' supply chain strategies, optimization, and integration of Artificial Intelligence.

H2: There are significant differences in supply chain performance metrics between companies that fully integrate AI technologies into their supply chains.

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H3: There is a significant correlation between the adoption rate of AI technologies and key performance indicators (KPIs).

H4: There is a significant correlation between the demographic profile of the respondents and the integration of artificial intelligence into pharmaceutical companies' supply chain operations.

METHODS AND MATERIALS

Research Design

This study utilized a quantitative research design, employing surveys to collect numerical data regarding AI adoption, supply chain strategies, and key performance indicators from pharmaceutical companies. A structured questionnaire derived from the research questions underwent pilot testing to ensure clarity and validity prior to distribution. Statistical methods, such as descriptive statistics, correlation, and regression analysis, were applied to analyze the data, revealing trends and relationships among the variables. The findings from the quantitative phase were integrated with qualitative insights, offering a well-rounded understanding of AI adoption and supply chain strategies, thereby strengthening the validity and depth of the study's conclusions and recommendations.

Participants and Sampling

The participants of this study consisted of 309 supply chain professionals, managers, and executives from pharmaceutical companies, selected through simple random sampling. This sampling method ensures that every company had an equal chance of being included, enhancing the representativeness of the findings. A structured questionnaire, developed with input from experts to ensure content validity and reliability, was used as the primary data collection tool. The survey was distributed electronically and through mail, gathering data on AI adoption, supply chain strategies, key performance indicators (KPIs), and organizational characteristics.

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The sample size of 309 was calculated using the Cochran formula, which effectively balances precision, confidence, and practicality. With a confidence level of 95% and a margin of error set at 5%, this formula considered the finite population of 1,560 pharmaceutical companies. This methodology ensures that the results obtained are both reliable and applicable to the wider industry. The collected data were analyzed using statistical methods, including mean and correlation analyses, to uncover trends and relationships among the variables. Additionally, secondary data from industry reports and databases enriched the findings, offering a well-rounded perspective on AI integration in pharmaceutical supply chain management, leading to informed conclusions and recommendations.

Data Collection

The researcher-designed questionnaire for this study on AI adoption in pharmaceutical supply chains captures critical data across several areas. It begins with demographic questions about company size, location, and operations, followed by detailed queries on AI adoption, focusing on the technologies implemented, specific applications used, and the perceived benefits and challenges. The survey also explores supply chain strategies, including inventory management, logistics, and procurement. Additionally, key performance indicators (KPIs) such as cost efficiency and delivery performance are examined. The questionnaire includes questions on leadership support, organizational culture, and data governance, and offers open-ended sections for qualitative insights.

Data Analysis

The data analysis for the study on AI adoption in pharmaceutical supply chains utilizes both quantitative and qualitative techniques. Quantitative data from surveys will be analyzed using SPSS, applying statistical methods such as descriptive statistics (mean, median, standard deviation), correlation, regression analysis, and ANOVA. Descriptive statistics summarize AI adoption rates, supply chain metrics, and organizational characteristics, while correlation and regression analyses explore relationships and predictors, such as AI's impact

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on cost efficiency. The integration of quantitative findings will provide deeper insights into AI adoption and supply chain management, aiding in theory development and practical implications for the pharmaceutical industry.

RESULTS

This portion presents the data gathered by the researcher with its corresponding analysis and Interpretation based on the study's problem.

The Current Supply Chain Strategies Employed by Pharmaceutical Companies in terms of Adoption Rate of AI Technologies, Cost Efficiency, Inventory Turnover, and On-time Delivery Performance

Table 1

Indicators	Mean	Descriptive Value
Adoption Rate of AI Technologies		
1. Pharmaceutical companies actively assess and implement AI technologies to optimize their supply chain processes.	4.35	E
2. Adopting AI technologies is increasingly prevalent among pharmaceutical companies to enhance supply chain efficiency.	4.10	E
3. Pharmaceutical companies prioritize the integration of AI technologies into their supply chain strategies to stay competitive.	3.87	E

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4. Continuous evaluation and improvement of AI adoption rates in the strategies employed by pharmaceutical companies.	4.12	E
5. Efforts to enhance the adoption rate of AI technologies are a crucial focus for pharmaceutical companies seeking to streamline their supply chains.	4.07	E
WEIGHTED MEAN	4.10	EMPLOYED
Cost Efficiency		
1. Cost efficiency is a primary objective guiding pharmaceutical companies' supply chain strategies to optimize key performance indicators.	4.80	HE
2. Pharmaceutical companies actively seek cost-saving opportunities throughout their supply chain operations to enhance key performance indicators.	4.67	HE
3. Continuous optimization of cost efficiency is a fundamental aspect of pharmaceutical supply chain management, contributing to enhanced key performance indicators.	4.15	E
4. Pharmaceutical companies regularly implement strategic initiatives to improve cost efficiency to elevate key performance indicators.	4.02	E
5. Efforts to enhance cost efficiency drive the decision-making process within pharmaceutical supply chain management, focusing on improving key performance indicators.	4.25	E
WEIGHTED MEAN	4.38	EMPLOYED
Inventory Turnover		

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1. Pharmaceutical companies prioritize efficient inventory turnover to minimize carrying costs and enhance cash flow, elevating key performance indicators.	4.18	E
2. Optimizing inventory turnover rates is a crucial strategy pharmaceutical companies employ to effectively meet demand and enhance key performance indicators.	4.57	HE
3. Regular monitoring and adjustment of inventory turnover rates are integral to pharmaceutical supply chain management and contribute to improved key performance indicators.	4.60	HE
4. Efforts to improve inventory turnover contribute to the agility and responsiveness of pharmaceutical supply chains.	4.13	E
5. Continuous evaluation and refinement of inventory turnover practices are essential	4.30	E
WEIGHTED MEAN	4.36	EMPLOYED
On-time Delivery Performance		
1. Maintaining high on-time delivery performance is a strategic imperative for pharmaceutical companies, directly impacting key performance indicators	4.45	E
2. Pharmaceutical companies prioritize reliability and punctuality in meeting delivery deadlines, aiming for improved key performance indicators	4.30	E
3. Efforts to enhance on-time delivery performance drive continuous improvement initiatives within		

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pharmaceutical supply chains, resulting in elevated key performance indicators	4.26	E
4. Meeting or exceeding on-time delivery targets is a key performance indicator for pharmaceutical supply chain management, and it positively reflects other key performance indicators.	4.17	E
5. Pharmaceutical companies actively invest in infrastructure and processes to ensure consistent on-time delivery performance, thereby enhancing key performance indicators	4.52	E
WEIGHTED MEAN	4.34	EMPLOYED
OVERALL MEAN	4.30	EMPLOYED
LEGEND INTERPRETATION: 1.00-1.49 Not Employed (NE); 1.50-2.49 Slightly Employed (SE); 2.50-3.49 Moderately Employed (ME); 3.50-4.49 Employed (E); 4.50-5.00 Highly Employed (HE)		

In recent years, integrating artificial intelligence (AI) into the pharmaceutical sector has driven transformative changes across drug discovery, development, and supply chain management. AI accelerates drug discovery by analyzing vast datasets, such as genomic and chemical information, to predict drug behavior, significantly reducing costs and time (Shokat & Ashfaq, 2023; Zhu, 2020). AI adoption within pharmaceutical supply chains enhances sustainability, optimizes clinical trials, and supports personalized medicine, improving both efficiency and patient outcomes (Tripathi et al., 2022; Sultana et al., 2023).

Despite its potential, challenges remain, particularly in China, where issues like data standardization and skilled labor shortages impact AI integration (Sampene & Nyirenda, 2024). However, AI significantly enhances cost efficiency and inventory management, offering

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companies a competitive edge by optimizing production and logistics and reducing development costs (Kulob, 2021; Harrer et al., 2019).

AI's application in inventory management minimizes waste, improves data accuracy, and speeds decision-making, leading to improved supply chain performance and customer satisfaction (Chowhurry, 2021; Foya, 2021). Moreover, AI-driven machine learning in drug discovery enhances precision in identifying drug targets and optimizing pharmacokinetics, further reducing R&D costs and improving patient care outcomes (Keller et al., 2019; Vora et al., 2023).

The Extent of Pharmaceutical Companies Integration of Artificial Intelligence (AI) Technologies into their Supply Chain Operations in Organizational Culture, Leadership Support, Data Quality and Governance, and Regulatory Compliance

Table 2

Indicators	Mean	Descriptive Value
Organizational Culture		
1. Pharmaceutical companies actively foster an organizational culture that promotes the seamless integration of AI technologies into their supply chain operations.	3.67	I
2. A culture of innovation and adaptability is cultivated within pharmaceutical companies to facilitate the widespread integration of AI technologies into supply chain processes.	4.10	I

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3. Efforts to promote collaboration and openness within organizational structures encourage adopting and utilizing AI technologies in pharmaceutical supply chains.	4.25	I
4. Leadership actively promotes an organizational culture that values experimentation and embraces AI technologies as integral components of supply chain optimization.	4.19	I
5. Pharmaceutical companies undertake continuous learning and development initiatives to ensure that their organizational culture aligns with the effective integration of AI technologies.	4.26	I
WEIGHTED MEAN	4.09	INTEGRATED
Leadership Support		
1. Pharmaceutical companies demonstrate strong leadership support for integrating AI technologies into their supply chain operations.	4.12	I
2. Leaders actively champion the adoption of AI technologies, providing resources and guidance to facilitate their seamless integration into pharmaceutical supply chains.	3.90	I
3. Leadership ensures clear communication and alignment of objectives to prioritize and support the integration of AI technologies within pharmaceutical supply chain operations.	4.10	I
4. Continuous engagement and endorsement from top-level management reinforce the importance of AI integration and drive momentum for change within pharmaceutical companies.	3.75	I
5. Leadership actively advocates for the strategic integration of AI technologies, recognizing their potential to enhance efficiency and effectiveness across supply chain processes.	4.03	I

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WEIGHTED MEAN	3.98	INTEGRATED
Data Quality and Governance		
1. Pharmaceutical companies prioritize establishing robust data quality and governance frameworks to support the effective integration of AI technologies into supply chain operations.	4.40	I
2. Data integrity and accuracy are paramount for pharmaceutical companies leveraging AI technologies to optimize supply chains.	4.35	I
3. Efforts to enhance data governance practices are undertaken to create the trust and reliability necessary for successfully integrating AI technologies.	4.12	I
4. Continuous monitoring and improvement of data quality standards are integral to pharmaceutical supply chain management, facilitating the seamless integration of AI technologies.	4.28	I
5. Pharmaceutical companies invest in advanced data management systems and processes to ensure compliance with regulatory requirements and support the effective integration of AI technologies.	4.10	I
WEIGHTED MEAN	4.25	INTEGRATED
Regulatory Compliance		
1. Pharmaceutical companies prioritize regulatory compliance as a critical aspect of integrating AI technologies into their supply chain operations	4.27	I
2. Compliance with regulatory standards and guidelines is rigorously maintained throughout the integration process to ensure the ethical and legal use of AI technologies.	4.15	I

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3. Industry-specific regulations and compliance requirements conduct efforts to integrate AI technologies into pharmaceutical supply chains	4.05	I
4. Regular audits and assessments are conducted to ensure that the integration of AI technologies complies with regulatory frameworks governing pharmaceutical supply chain operations	4.40	I
5. Pharmaceutical companies proactively engage with regulatory bodies to stay informed about evolving requirements and adapt their AI integration strategies accordingly	4.32	I
WEIGHTED MEAN	4.23	INTEGRATED
OVERALL MEAN	4.14	INTEGRATED
LEGEND INTERPRETATION: 1.00-1.49 Not Integrated (NI); 1.50-2.49 Slightly Integrated (SI); 2.50-3.49 Moderately Integrated (MI); 3.50-4.49 Integrated (I); 4.50-5.00 Highly Integrated (HI)		

Artificial Intelligence (AI) has reshaped leadership paradigms and organizational dynamics, offering advantages in efficiency and decision-making. While AI enhances operations, human leadership remains crucial for fostering a motivated, ethically run workforce. AI enables pharmaceutical companies to analyze vast amounts of data, driving informed decisions based on empirical evidence rather than intuition. This integration empowers leaders to optimize market strategies, improve supply chain operations, and enhance product quality (King, 2023).

AI plays a vital role in quality management, automating processes such as in-process inspections and predictive maintenance, reducing costs, and preventing wastage (Ataman,

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 2023). In pharmaceutical companies, AI-driven Quality Management Systems (QMS) help ensure regulatory compliance by analyzing data, navigating global standards, and identifying potential risks (Haziqa, 2023). The application of AI in pharmacovigilance streamlines drug safety monitoring by automating adverse drug reaction detection and reporting, enhancing the efficiency and accuracy of the process (Farombi & Klaus, 2024).

The integration of AI in pharmaceutical regulatory affairs is set to revolutionize compliance, making it more adaptive to rapid technological advancements (Han, 2023). A balanced approach, combining AI with human leadership, will foster innovation, ethical practices, and operational excellence, ensuring sustainable growth in an increasingly competitive industry.

The Significant Relationship between the Current Supply Chain Strategies employed by Pharmaceutical Companies and the Integration of Artificial Intelligence (AI) Technologies into their Supply Chain Operations

Table 3

<i>Correlation Analysis -two sample assessing equal balances</i>								
<i>Supply Chain Strategies Employed</i>	<i>Integration of artificial intelligence in supply chain operations</i>							
	<i>Organizational Structure</i>		<i>Leadership Support</i>		<i>Data Quality and Governance</i>		<i>Regulatory Compliance</i>	
	<i>r value</i>	<i>Sig</i>	<i>r value</i>	<i>Sig</i>	<i>r value</i>	<i>Sig</i>	<i>r value</i>	<i>Sig</i>
<i>Adoption Rate of AI technology</i>	<i>0.182**</i>	<i>0.005</i>	<i>0.344**</i>	<i>0.001</i>	<i>0.231</i>	<i>0.003</i>	<i>0.347</i>	<i>0.003</i>
	<i>n=309</i>		<i>n=309</i>		<i>n=309</i>		<i>n=309</i>	
<i>Cost efficiency</i>	<i>.186**</i>	<i>0.007</i>	<i>.239**</i>	<i>0.005</i>	<i>.168*</i>	<i>0.017</i>	<i>.255 *</i>	<i>0.007</i>
	<i>n-309</i>		<i>n=309</i>		<i>n=309</i>		<i>n-309</i>	
<i>Inventory turnover</i>	<i>0.079</i>	<i>0.325</i>	<i>.203**</i>	<i>0.002</i>	<i>.340**</i>	<i>0.009</i>	<i>.193*</i>	<i>0.004</i>
	<i>n-309</i>		<i>n-309</i>		<i>n=309</i>		<i>n=309</i>	
<i>On-time Delivery Performance</i>	<i>.212**</i>	<i>0.002</i>	<i>.385**</i>	<i>0.007</i>	<i>.425**</i>	<i>0.005</i>	<i>.372**</i>	<i>0.006</i>
	<i>n=309</i>		<i>n=309</i>		<i>n=309</i>		<i>n=309</i>	
<i>Pooled Variance = 0.112</i>								
<i>Variance</i>								
<i>Strategies Employed = 0.21824</i>								
<i>Artificial intelligence integration = 0.10278</i>								
<i>Mean</i>								
<i>strategies employed = 3.8554</i>								
<i>artificial intelligence</i>								
<i>integration = 3.7820</i>								
<i>Overall sig</i>	<i>0.168</i>							
<i>p-value</i>	<i>.005</i>							

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AI integration in pharmaceutical companies' supply chain strategies has proven highly effective in enhancing operational efficiency and responsiveness. AI technologies, such as machine learning (ML) and data analytics, enable precise demand forecasting, inventory management, and route optimization. In drug discovery, AI accelerates research by analyzing large datasets, predicting outbreaks, and reducing manufacturing downtime (Morgan et al., 2023). AI-powered analytics help pharmaceutical companies maintain optimal inventory levels, minimize stockouts, and automate processes to reduce human error.

AI also supports real-time data collection and analytics for distribution, enabling pharmaceutical companies to optimize delivery routes, track shipments, and improve customer satisfaction. By aligning inventory with demand forecasts, AI helps reduce excess inventory while ensuring timely deliveries (Balthrop, 2023). In quality control, AI monitors production, detects potential risks, and enhances decision-making by analyzing data across the supply chain (Chowdhury et al., 2023).

AI's role extends to supplier management, where it evaluates suppliers based on cost, quality, and sustainability, enabling pharmaceutical companies to create optimal supplier portfolios (Johnson et al., 2022). Furthermore, AI-generated inventory policies reduce costs through just-in-time strategies and enhance logistics by analyzing real-time traffic and weather data for efficient transportation (Klumpp & Ruiner, 2022).

The Optimization and Integration of Pharmaceutical Companies in Mitigating Potential Risk in terms of Market Dynamics, Technological Advancement, Supply Chain Resilience, Customer Satisfaction, and Environmental Sustainability

Table 4

Indicators	Mean	Descriptive Value
Market Dynamics		

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1. Pharmaceutical companies actively monitor and analyze market dynamics to inform optimization and integration practices to mitigate potential risks.	4.12	P
2. Continuous assessment of market trends and competitor activities guide proactive measures undertaken by	4.23	P
3. Strategic partnerships and collaborations are formed based on insights derived from market analysis to enhance risk mitigation efforts within pharmaceutical supply chains.	4.10	P
4. Agile decision-making processes are employed to adapt supply chain strategies in response to fluctuating market dynamics, minimizing potential risks for pharmaceutical companies	4.34	P
5. Pharmaceutical companies leverage predictive analytics and scenario planning to anticipate and address potential risks arising from shifts in market dynamics.	4.45	P
WEIGHTED MEAN	4.25	PRACTICED
Technological Advancement		
1. Pharmaceutical companies prioritize technological advancement as a cornerstone of their optimization and integration practices to mitigate potential risks	4.60	HP
2. Continuous investment in cutting-edge technologies such as AI, IoT, and blockchain enables pharmaceutical companies to enhance risk mitigation capabilities across supply chain operations	4.16	P
3. Cross-functional teams collaborate to identify and implement innovative technological solutions that	4.30	P

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address vulnerabilities and enhance resilience against potential risks.		
4. Regular assessments of emerging technologies inform strategic decision-making processes within pharmaceutical companies, driving continuous improvement and adaptation to mitigate risks.	4.21	P
5. Pharmaceutical companies actively engage with technology partners and industry experts to stay ahead of technological advancements, strengthening their ability to mitigate risks effectively.	4.36	P
WEIGHTED MEAN	4.37	PRACTICED
Supply Chain Resilience		
1. Pharmaceutical companies implement robust supply chain resilience strategies as part of their optimization and integration practices to mitigate potential risks.	4.15	P
2. Diversification of suppliers and distribution channels is prioritized to enhance resilience and minimize the impact of disruptions on pharmaceutical supply chains.	4.27	P
3. Scenario-based risk assessments are conducted to identify vulnerabilities and develop contingency plans that bolster pharmaceutical companies' supply chain resilience.	4.32	P
4. Investments in redundant infrastructure and logistics capabilities contribute to the resilience of pharmaceutical supply chains, ensuring continuity amidst unforeseen challenges.	3.89	P
5. Regular stress testing and simulation exercises are undertaken to evaluate the effectiveness of resilience	4.38	P

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strategies and identify areas for improvement within pharmaceutical supply chains.		
WEIGHTED MEAN	4.20	PRACTICED
Customer Satisfaction		
1. Pharmaceutical companies prioritize customer satisfaction and incorporate it into their optimization and integration practices to mitigate potential risks.	4.27	P
2. Continuous feedback mechanisms are established to gauge customer sentiment and preferences, informing proactive measures to address potential risks to satisfaction within pharmaceutical supply chains.	4.61	HP
3. Customer-centric supply chain design principles are adopted to enhance responsiveness and flexibility, mitigating risks associated with fluctuations in customer demand for pharmaceutical products	4.18	P
4. Providing customers support interactions for complaints and monitoring interactions, providing precise guidelines for support agents, and creating quicker service.	4.12	P
5. The customer service approach provides multiple communication channels for customers to interact with the company on feedback and requests that must be solved in a given period.	4.45	P
WEIGHTED MEAN	4.33	PRACTICED
Environmental Sustainability		
1. Artificial intelligence addresses the pharmaceutical industry's ecological impact through waste reduction, resource conservation, and innovation approaches to enhance environmental sustainability.	4.48	P

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2. AI helps discover sustainable drugs to lessen the environmental footprint on the clinical industry and avoid possible hazards and unpredictable barriers in sustaining the chemical environment.	4.35	P
3. The integration of AI can support pharmaceutical companies' green chemistry process to aid product manufacturing and ensure safety from toxic environments.	4.21	P
4. AI optimization addresses manufacturing devices, enabling the production of customized items to ensure environmentally sustainable approaches.	4.37	P
5. AI helps accelerate the identification of potential drugs and optimizes molecular drug designs, predicting drug efficiency and safety towards environmental sustainability.	4.54	HP
WEIGHTED MEAN	4.39	PRACTICED
OVERALL MEAN	4.31	PRACTICED
LEGEND INTERPRETATION: 1.00-1.49 Not Practiced (NP); 1.50-2.49 Slightly Practiced (SP); 2.50-3.49 Moderately Practiced (MP); 3.50-4.49 Practiced (P); 4.50-5.00 Highly Practiced (HP)		

The pharmaceutical industry continues to innovate, with Artificial Intelligence (AI) playing a crucial role in advancing research, development, and patient care. AI's integration into the supply chain is transforming risk mitigation strategies, particularly in market dynamics, technological advancement, and customer satisfaction. AI enhances risk management by predicting potential disruptions, such as supplier insolvency or natural disasters, and developing resilient strategies to ensure business continuity (Mentzer et al., 2021).

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In customer satisfaction, AI-driven chatbots provide personalized updates, improving customer experiences and retention (Gigor, 2022). AI also supports environmental sustainability by optimizing resource allocation, predicting material life cycles, and facilitating closed-loop systems to reduce waste (Hahn & Tampe, 2021). Moreover, AI can help shift the industry towards a servitization model, offering customized services by analyzing customer data and predicting product maintenance needs.

Regarding environmental sustainability, AI enables pharmaceutical companies to monitor supply chain operations and identify risks, ensuring ethical compliance and transparency (Richey & Davis-Sramek, 2022). Additionally, AI mitigates supply chain disruptions during disasters by optimizing pharmaceutical delivery and resource allocation (Kwon & Kim, 2018). It means that AI's integration into the pharmaceutical supply chain enhances resilience, sustainability, and efficiency, helping companies navigate risks and foster innovation in a rapidly evolving industry.

The Impact of Artificial Intelligence Adoption on Key Performance Indicators of Pharmaceutical Companies in terms of Delivery Fulfilment, Quality System Effectiveness, Change Control, Compliance Quest, and Supply Chain Robustness

Table 5

Indicators	Mean	Descriptive Value
Delivery Fulfilment		
1. Pharmaceutical companies are experiencing the effectiveness of Artificial intelligence (AI) in delivering products, from optimizing schedules to improving decision-making.	4.42	I

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2. Companies are provided with route optimization by adopting AI to select the most efficient direction and avoid product conveyance delays.	4.34	I
3. Companies receive forecast surveys from AI on drops in demand, using data from ordering patterns, market behavior, competitors, and delivery trends.	4.65	HI
4. Artificial adoption aids companies in predicting items that need storage and will be ordered soon, allowing warehouses to speed up and pack distribution channels.	4.27	I
5. Companies obtain easy access to logistic data through AI adoption of product data, demand, manufacturing, and supplier data, resulting in robust delivery.	4.31	I
WEIGHTED MEAN	4.40	IMPACT
Quality System Effectiveness		
1. The adoption of Artificial Intelligence (AI) helps companies analyze vast amounts of data quality and accuracy, identifying patterns and easily noted defective items to ensure quality assurance.	4.10	I
2. The integration of AI aids companies in improving speed and optimization by ensuring efficiency and analyzing the root cause of defective items.	4.47	I
3. Adopting AI provides companies with an analytical platform to analyze vast amounts of production data to identify inefficiencies and areas that need improvement in total quality management (TQM).	4.23	I
4. Using AI helps improve companies' manufacturing quality control by automating the inspection process and enhancing product quality.	4.20	I

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5. Companies can quickly analyze vast amounts of visual data through AI adoption in the manufacturing process and real-time decisions on product quality.	4.34	I
WEIGHTED MEAN	4.27	IMPACT
Change Control and Compliance Quest		
1. Integrating Artificial Intelligence (AI) into organizational processes brings transformation through data-driven decision-making, adaptability, and heightened forces on ethical considerations.	4.35	I
2. Companies improve customer engagement, organizational data analysis, automation processes, strategic recommendations, and enhanced compliance decision-making through AI.	4.42	I
3. AI provides advancements in task automation, streamlining repetitive and mundane tasks and freeing employees to focus on creative tasks and organizational change.	4.45	I
4. Adopting AI offers companies significant data insights and creates detailed reports to help them determine whether they are on the right track toward change control.	4.70	HI
5. Companies boost their productivity by adopting AI to reduce human error and make better-driven decisions for the entire organization regarding compliance and change control.	4.56	HI
WEIGHTED MEAN	4.50	IMPACT
Supply Chain Robustness		
1. The adoption of AI ensures adequate supply chain robustness through its vast data from sales forecast supply, inventory, and supply channels.	4.21	I

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2. Artificial intelligence offers companies a range of powerful tools and capabilities that make businesses anticipate and respond to disruption in transportation effectively.	4.36	I
3. Adopting AI aids companies in enhancing supply chain visibility, optimizing inventory management, and streamlining the logistics chain.	4.29	I
4. The integration of AI enhances customer satisfaction with robust delivery and contributes to operational stability, cost efficiency, and risk mitigation.	4.16	I
5. Companies can easily detect supply chain disruption caused by suppliers, workers, shortages, shipping delays, and scheduling through AI.	4.43	I
WEIGHTED MEAN	4.29	IMPACT
OVERALL MEAN	4.37	IMPACT
LEGEND INTERPRETATION: 1.00-1.49 Not Impact (NI) ; 1.50-2.49 Slightly Impact (SI) ; 2.50-3.49 Moderately Impact (MI) ; 3.50-4.49 Impact (I) ; 4.50-5.00 Highly Impact (HI)		

AI is essential for enhancing delivery fulfillment and logistics planning in the pharmaceutical sector. By leveraging sophisticated algorithms and machine learning, AI can evaluate various factors, including traffic patterns, weather conditions, and transportation expenses, to optimize delivery routes. This optimization ensures timely and cost-efficient distribution while also minimizing environmental impact (Chen, 2023). Consequently, it fosters more sustainable drug distribution practices, decreases carbon emissions, and boosts operational efficiency. Furthermore, AI improves order fulfillment accuracy by automating tasks such as packing, labeling, and tracking, which helps to reduce errors and guarantees timely delivery to both healthcare providers and patients (Alqahtani, 2022).

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AI's integration into pharmaceutical quality assurance streamlines processes, ensuring products meet strict regulatory standards. AI systems can analyze large datasets to identify trends and abnormalities, enabling real-time corrections and improving production quality (Mahato, 2023). These systems also aid in regulatory compliance by automating documentation and tracking discrepancies in production processes (Kim, 2023).

The impact of AI on key performance indicators (KPIs) in the pharmaceutical industry is profound. AI improves drug development processes by accelerating data analysis and identifying trends that would otherwise go unnoticed (Yarragunta, 2022). As the industry continues to evolve, AI's role in supply chain management, regulatory compliance, and production optimization will be increasingly essential for efficiency and innovation.

The Challenges in Integrating and Optimizing Artificial Intelligence towards Key Performance Indicators (KPIs) in terms of Delivery Fulfillment, Quality System Effectiveness, Change Control and Compliance, and Supply Chain Robustness

Table 6

Indicators	Mean	Descriptive Value
Delivery Fulfillment		
1. Companies suffer from high maintenance costs when integrating and optimizing AI for their crucial performance in product delivery.	4.89	HS
2. They encounter difficulty in complex data sources since AI heavily relies on data diversity.	4.48	S
3. Companies lack a clear transformation strategy for inputting AI data storage in delivery fulfillment, which results in resource waste and a lack of direction.	4.30	S

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4. AI works in isolation, which leads to isolated data and prevents its system from accessing the comprehensive information needed for delivery.	4.25	S
5. Companies' inability to secure data usage may lead to unpredicted misleading information about product delivery to suppliers and customers.	4.37	S
WEIGHTED MEAN	4.46	SERIOUS
Quality System Effectiveness		
1. Companies encounter incomplete data sets that lead to biased AI prediction and make incorrect quality system decisions.	4.42	S
2. Companies experience errors in inputting data, which affects the manufacturing process to enhance product quality and output.	4.55	HS
3. Insufficient data for AI model delivery results in misleading information and ineffective quality results.	4.20	S
4. Poor indicator performance AI-driven automation results in ineffective productivity in quality systems.	4.38	S
5. Companies struggle to justify the upfront cost and allocate resources for a successful quality system.	4.34	S
WEIGHTED MEAN	4.38	SERIOUS
Change Control and Compliance		
1. Integrating compliance AI automation tools poses a significant challenge to legal systems that sync with modern AI, making integration complex and unfeasible.	4.35	S
2. Companies encounter unmitigated and uncontrollable AI risk in exposing company investments in cybersecurity and failure to protect confidential information.	4.13	S

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3. Suffer high cost of implementation and issues on data security and legal issues	4.24	S
4. Optimizing AI results in resistance to change, entrenched organizational cultures, and implementation challenges.	4.30	S
5. It generates ethical issues in the organization, including machine bias, less human control, and high workplace job displacement.	4.62	HS
WEIGHTED MEAN	4.33	SERIOUS
Supply Chain Robustness		
1. Challenges in AI data inaccessibility in the supply chain that drives decision-making and operations are limited.	4.41	S
2. The automation of AI in logistics leads to workforce displacement, such as order processing, transportation, and supply chains taken over by AI-powered systems.	4.64	HS
3. Embracing AI creates issues due to the lack of a governance framework, which significantly barriers its successful implementation in the supply chain.	4.36	S
4. The AI-driven solution is weakened by a lack of data, which will damage supply chains by misleading information to sustain logistics.	4.29	S
5. Optimizing AI supply chain software creates disparities among suppliers unwilling to compromise and prefer the traditional supply chain system.	4.77	HS
WEIGHTED MEAN	4.49	SERIOUS
OVERALL MEAN	4.42	SERIOUS
LEGEND INTERPRETATION: 1.00-1.49 Not Serious (NS); 1.50-2.49 Slightly Serious (SS); 2.50-3.49 Moderately Serious (MS); 3.50-4.49 Serious (S); 4.50-5.00 Very Serious (VS)		

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In today's competitive market, pharmaceutical companies recognize the importance of improving supply chain performance to maintain a competitive edge. Managers must balance forecasting, procurement, stock levels, and marketing strategies to meet organizational goals. Supply chain management (SCM) has become critical as companies face challenges such as shorter product life cycles, fluctuating customer demands, and rising manufacturing and shipping costs. Effective SCM helps pharmaceutical companies accelerate innovation, optimize resource utilization, reduce costs, and enhance profitability (Moosivand et al., 2019).

Artificial intelligence significantly impacts drug discovery; however, its effectiveness relies heavily on the availability of high-quality data and the resolution of ethical issues. Key challenges include the accessibility of data, potential biases, and ethical implications related to AI-driven decisions, including the selection of clinical trials and the drug development process (Vamathevan et al., 2019; Shimao et al., 2022). Strategies such as data augmentation and explainable AI (XAI) can enhance data diversity and provide greater transparency in AI predictions (Arrieta et al., 2019).

AI's integration into the pharmaceutical supply chain enhances efficiency in quality control, automation, and regulatory compliance. However, it also raises concerns about job displacement, data privacy, and security (Karimian et al., 2022). To harness AI responsibly, pharmaceutical companies must implement diverse, bias-free data practices, regularly audit AI systems, and establish robust data privacy protocols to maintain ethical standards and public trust.

DISCUSSION

The study's findings reveal that pharmaceutical companies are actively employing AI technologies across their supply chain strategies, with an overall adoption rate of 4.30, signifying that AI is effectively utilized to enhance cost efficiency, inventory turnover, and on-

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time delivery performance. Among these, cost efficiency scored the highest at 4.38, suggesting that AI plays a crucial role in optimizing operational costs. This aligns with existing literature, which highlights AI's potential to streamline pharmaceutical supply chains (Moosivand et al., 2019). However, the AI adoption rate in organizational culture and leadership support is slightly lower (4.09 and 3.98), indicating room for improvement in fostering a more AI-integrated organizational culture.

A positive correlation (0.168) was found between AI integration and current supply chain strategies, demonstrating that AI positively influences performance metrics such as cost efficiency and delivery fulfillment. This agrees with previous studies that show AI's ability to enhance supply chain resilience and customer satisfaction (Gonzales et al., 2023). Yet, challenges persist, with a severe rating of 4.42 for integrating AI into key performance indicators, particularly in delivery fulfillment (4.46) and supply chain robustness (4.49). These challenges may stem from data quality issues and ethical concerns, as Vamathevan et al. (2019) noted. While AI adoption positively impacts pharmaceutical supply chain performance, overcoming data quality, governance, and ethical concerns will be crucial for future optimization.

CONCLUSION

This research examined how integrating Artificial Intelligence (AI) into the pharmaceutical companies' supply chain strategies affects key performance indicators (KPIs), including cost efficiency, inventory turnover, delivery fulfillment, and supply chain resilience. The results indicate that AI substantially improves these performance metrics, supporting the hypothesis that adopting AI leads to enhanced operational efficiency and a competitive edge in the pharmaceutical sector.

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AI integration has notably improved cost efficiency, inventory management, and on-time delivery, highlighting its value in optimizing supply chain processes. A positive relationship between AI adoption and supply chain strategies further supports AI's role in boosting performance. However, challenges remain, particularly in delivery fulfillment and supply chain resilience, where obstacles like data quality and governance issues must be addressed.

These findings have crucial implications for pharmaceutical companies. While AI offers substantial benefits in streamlining operations and enhancing performance, fully realizing its potential requires stronger integration into organizational culture, leadership support, and ethical governance. Companies must focus on overcoming existing challenges to maximize AI's capabilities and ensure long-term operational success. These results emphasize the strategic importance of AI in modern supply chain management, offering practical insights for improving competitiveness and sustainability in the pharmaceutical sector.

RECOMMENDATIONS

Based on the findings of the study and the conclusions generated, the researcher recommends the following:

1. Pharmaceutical companies may foster collaboration with research institutions, education systems, and other industry stakeholders to establish an innovative and sophisticated infrastructure for data sharing and collaboration projects, leveraging knowledge sharing and resources to enhance supply chain strategies.
2. The industries may promote inter-agency programs that combine expertise in Artificial Intelligence and pharmaceutical facilities. These programs can foster continuous learning and adaptation to develop the full potential of AI integration across the entire pharmaceutical ecosystem.

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3. The companies may develop a centralized Artificial Intelligence infrastructure that aggregates and anonymizes data from various pharmaceutical companies to enhance the industry's collective intelligence and innovate supply chain operations and AI integration.
 4. Government authorities and regulatory bodies may refine policies based on real-world scenarios and scientific evidence to ensure the integration of Artificial Intelligence in pharmaceutical processes aligns with society's standards and its expectations within the ethical issues to mitigate possible risk potentials.
 5. Pharmaceutical companies may develop a comprehensive Contingency Plan anchored on robust regulation and incentives to enhance the utilization of Artificial intelligence-driven technology to improve their key performance indicators (KPI).
 6. May this result be shared with local, national, or international publications and conferences, where this platform could serve as a hub for pooled insights, best practices, and AI-driven technology using advanced discoveries and innovative strategies on a broader scale.

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