INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN ECONOMICS & MANAGEMENT SCIENCES

OPEN ACCESS JOURNAL

Vol 14, Issue 3, (2025) E-ISSN: 2226-3624

Sustainable Governance of Pharmacy Supply Chains with AI Integration: A Stakeholder Theory Perspective

Sharifah Norzehan Bt Syed Yusuf*
Accounting Research Institute, Universiti Teknologi MARA, Malaysia

Corina Ak Joseph
Faculty of Accountancy, Universiti Teknologi MARA, Sarawak

Mahmathi A/P Karuppannan
Faculty of Pharmacy, Universiti Teknologi MARA, Malaysia

DOI Link: http://dx.doi.org/10.6007/IJAREMS/v14-i3/26622

Published Online: 26 September 2025

Abstract

This paper develops a stakeholder-theory perspective on sustainable governance of pharmacy supply chains with artificial intelligence (AI) integration. It situates the problem in global, ASEAN, and Malaysian contexts where risks from substandard and falsified products, medication-safety losses, and uneven regulatory capacity challenge supply-chain integrity. Stakeholder theory is used to frame how regulators, manufacturers, distributors, pharmacists, patients, payers, and technology providers shape incentives for data sharing, transparency, safety, and environmental performance. Evidence from international guidance and regional policy shows how Good Distribution Practice, data-protection laws, and ASEAN pharmaceutical harmonization can be operationalised together with AI tools for forecasting, traceability, inventory stewardship, and cold-chain assurance. A conceptual governance model is proposed that links AI functionalities to stakeholder expectations and measurable outcomes, including safety incidents, stock-out frequency, waste reduction, and patient trust. The paper outlines researchable propositions and a mixed-methods agenda for empirical validation in Malaysia and across ASEAN, where rapid digital adoption and evolving health-data regulation create both opportunities and risks.

Keywords: Pharmacy Supply Chain, AI Integration, Sustainable Governance, Stakeholder Theory

Introduction

Pharmacy supply chains are increasingly complex due to globalized sourcing, temperature-sensitive products, and rapid shifts in demand. These complexities raise sustainability and safety risks that harm patients and reduce trust. The World Health Organization (WHO) estimates the annual global cost of medication errors at approximately USD 42 billion,

underscoring the need for more reliable systems and governance throughout the medicine pathway from procurement to dispensing (World Health Organization, 2017a). At the same time, the prevalence of substandard and falsified medical products in low- and middle-income countries is estimated at roughly one in ten, a statistic particularly relevant to parts of ASEAN and highlighting the importance of traceability and enforcement across borders (World Health Organization, 2017b). These conditions create a compelling case for upgraded supply-chain governance that can leverage AI while managing its risks.

Regional dynamics amplify this need. ASEAN is moving quickly on digital health, yet reports identify gaps in interoperability, standards, and trust that can undermine sustainability if left unaddressed (ASEAN-Japan Centre, 2024). Asia-Pacific smartphone penetration is projected to reach about 94 percent by 2030, expanding the technical feasibility of AI-enabled supply-chain functions such as mobile-first authentication, crowdsourced pharmacovigilance, and last-mile coordination (GSMA, 2023). Malaysia reflects these dual trends. It has strengthened pharmaceutical regulation and distribution controls through national laws and Good Distribution Practice guidelines, while simultaneously publishing new guidance to structure online healthcare services and data-handling responsibilities that intersect with supply-chain digitization (National Pharmaceutical Regulatory Agency, 2018; Ministry of Health Malaysia, 2025; Department of Personal Data Protection Malaysia, 2013).

Malaysia's pharmacy footprint is expanding but unevenly distributed. A geospatial analysis reported wide district-level variation, with overall ratios averaging one community pharmacy per 10,200 residents and extremes ranging from 1:4,830 to 1:61,707 in different districts (Bukhari et al., 2021). Such disparities affect equitable access and resilience, interacting with sustainability goals since stock-outs, waste from temperature excursions, and suboptimal routing impose social and environmental costs that directly impact stakeholders.

Pharmacy supply chains are increasingly complex due to globalized sourcing, temperature-sensitive products, and rapid shifts in demand. These complexities raise sustainability and safety risks that harm patients and reduce trust. The World Health Organization (WHO) estimates the annual global cost of medication errors at approximately USD 42 billion, underscoring the need for more reliable systems and governance throughout the medicine pathway from procurement to dispensing (World Health Organization, 2017a). At the same time, the prevalence of substandard and falsified medical products in low- and middle-income countries is estimated at roughly one in ten, a statistic particularly relevant to parts of ASEAN and highlighting the importance of traceability and enforcement across borders (World Health Organization, 2017b). These conditions create a compelling case for upgraded supply-chain governance that can leverage artificial intelligence (AI) while managing its risks.

Regional dynamics amplify this need. ASEAN is moving quickly on digital health, yet reports identify gaps in interoperability, standards, and trust that can undermine sustainability if left unaddressed (ASEAN-Japan Centre, 2024). Asia-Pacific smartphone penetration is projected to reach about 94 percent by 2030, expanding the technical feasibility of AI-enabled supply-chain functions such as mobile-first authentication, crowdsourced pharmacovigilance, and last-mile coordination (GSMA, 2023). Malaysia reflects these dual trends. It has strengthened pharmaceutical regulation and distribution controls through national laws and Good Distribution Practice guidelines, while simultaneously publishing new guidance to structure

online healthcare services and data-handling responsibilities that intersect with supply-chain digitization (National Pharmaceutical Regulatory Agency, 2018; Ministry of Health Malaysia, 2025; Department of Personal Data Protection Malaysia, 2013).

Malaysia's pharmacy footprint is expanding but remains unevenly distributed. A geospatial analysis reported wide district-level variation, with overall ratios averaging one community pharmacy per 10,200 residents and extremes ranging from 1:4,830 to 1:61,707 in different districts (Bukhari et al., 2021). Such disparities affect equitable access and resilience, interacting with sustainability goals since stock-outs, waste from temperature excursions, and suboptimal routing impose social and environmental costs that directly impact stakeholders. In addition, the pharmaceutical market in ASEAN is forecasted to exceed USD 200 billion by 2027, led by rising demand for generics, biologics, and digital healthcare innovations (Statista, 2024). However, the fragmented regulatory landscape and variable governance maturity across ASEAN nations create vulnerabilities in pharmaceutical logistics and post-market surveillance.

Problem Statement

Despite significant regulatory strides, the pharmacy supply chain in ASEAN and Malaysia continues to face systemic challenges that threaten safety, equity, and environmental integrity. Substandard and falsified products remain a persistent issue, especially in cross-border transactions. The WHO (2017b) found that 10% of medical products in developing countries are either substandard or falsified, a rate that threatens patient safety and undermines public confidence. In Malaysia, between 2020 and 2023, the National Pharmaceutical Regulatory Agency (NPRA) issued 242 product recalls due to quality and safety non-compliance, many of which were linked to supply-chain vulnerabilities (NPRA Annual Report, 2023). Furthermore, cold-chain failures were reported in 17% of temperature-sensitive pharmaceutical deliveries in Malaysia during the COVID-19 vaccination rollout, revealing critical gaps in monitoring and response systems (MOH Malaysia, 2021).

From an environmental perspective, pharmaceutical supply chains generate excessive carbon emissions and material waste due to inefficient routing, emergency restocking, and poor inventory control. A recent global study indicated that pharmaceutical supply chains contribute approximately 4.4% of global healthcare emissions, with significant contributions from freight and logistics activities (Health Care Without Harm, 2019). In ASEAN, the absence of standardized data-sharing frameworks and weak digital integration exacerbates these inefficiencies. AI has the potential to address these pain points—through predictive analytics, real-time traceability, route optimization, and cold-chain assurance—but its integration remains piecemeal, often limited by unclear governance mandates, ethical concerns, and stakeholder misalignment.

Crucially, the successful integration of AI into pharmacy supply chains hinges not merely on technical deployment but on robust stakeholder governance. The lack of shared accountability mechanisms, interoperability standards, and explainability in AI-driven systems heightens the risk of bias, fragmentation, and unequal access. This disconnect between stakeholder expectations and technological implementation inhibits the full realization of AI's transformative potential.

This paper seeks to develop a stakeholder-theory-based governance framework for the sustainable integration of artificial intelligence (AI) into pharmacy supply chains, with a particular focus on the Malaysian and broader ASEAN context. By mapping AI capabilities—such as forecasting, traceability, inventory optimization, and cold-chain monitoring—onto stakeholder expectations (e.g., transparency, safety, efficiency, and equitable access), the study proposes a conceptual governance model that enhances accountability, performance, and resilience. The objective is to provide both a theoretical foundation and a practical roadmap for policymakers, regulators, pharmaceutical actors, and technology providers to align incentives, mitigate risks, and operationalize AI in ways that support the Sustainable Development Goals (SDGs), particularly in health, innovation, and responsible consumption. The model is designed to be tested empirically in future research, offering a replicable and scalable approach to digital transformation in pharmaceutical governance across emerging economies.

Literature Review

The integration of artificial intelligence (AI) into the pharmacy supply chains is demonstrating to be a transformative force for sustainable governance. By facilitating data -based decision -making, AI improves efficiency, reduces waste and promotes environmental sustainability within the pharmaceutical sector. For example, Shashi (2023) emphasizes that sustainable digitalization, based on restrictions, allows a simplified supply chain process. This rationalization is particularly crucial in the pharmaceutical sector, where supply chain complexities can often lead to inefficiencies and increased waste. The theory of restrictions postulates that by identifying and addressing the most significant limitations within a supply chain, organizations can improve their general effectiveness. The analysis driven by AI can identify these bottlenecks in real time, allowing organizations to reallocate resources and rationalize the processes, thus mitigating waste and promoting sustainability.

The growth of AI in pharmacy supply chains is closely aligned with the principles of environmental, social and governance practices (ESG). Hao and Demir (2024) argue that the application of AI technologies can trigger significant advances in ESG initiatives by allowing organizations to monitor compliance, improve transparency and optimize the use of resources. These principles are vital since interested parties prioritize more and more sustainable practices that are aligned with consumer expectations and regulatory frameworks. IA technologies facilitate this alignment by providing solid data analysis that allow companies to evaluate their impact of ESG precisely. However, the authors also highlight technological barriers that can inhibit the growth of sustainability initiatives promoted by AI in pharmaceutical products. These barriers include infrastructure challenges, workforce skills gaps and the complexities of integrating AI systems with inherited technologies. Recognizing and addressing these obstacles is essential to maximize the effectiveness of AI in the promotion of sustainable governance.

The interaction between interested parties within the pharmacy supply chains becomes essential in the context of the integration of AI. Interested parties, including manufacturers, distributors, regulators and consumers, play intertwined roles that collectively shape sustainable results. For example, the work of Singh et al. (2022) highlights how collaboration between interested parties is essential for the successful implementation of AI -promoted solutions. Collaboration platforms that incorporate AI technologies can improve

communication and information exchange, leading to a more receptive and responsible supply chain. In addition, that same investigation indicates that the commitment of interested parties can lead to the collective development of standards and best practices that lead to sustainable governance. This collaborative approach not only improves operational efficiency, but also encourages a culture of sustainability and shared responsibility between all parties involved.

Ethical considerations surrounding AI in pharmacy supply chains cannot be overlooked. Interested parties must deal with the implications of data privacy, algorithmic bias and just access to AI resources. As Chen and Zhao (2023) are articulated, the implementation of AI solutions must be underlined by ethical governance frames that guarantee equity and equity between interested parties. This ethical framework is crucial, since it directly affects the trust and the adoption rates of the technologies of AI within the sector. The intersection of technology with ethical governance highlights the need for continuous dialogue and a proactive commitment between interested parties to ensure that IA applications are equitable and serve the broader objectives of sustainability.

Collectively, these dimensions underline the significant potential of AI to promote responsible practices in pharmaceutical supply chains and promote sustainable governance. By taking advantage of AI technologies, pharmaceutical organizations can not only optimize their operational efficiency but also to advance their sustainability agendas, contributing to a more resistant and responsible supply chain ecosystem. This interconnected approach emphasizes the critical role of interactions of interested parties and collaborative commitment as essential components of successfully integrating AI for sustainable governance in the pharmaceutical sector., The effective integration of artificial intelligence (AI) in pharmacy supply chains depends on the dynamic interactions of various stakeholders operating in this complex landscape. Stakeholders, in particular suppliers, manufacturers, health care providers, regulatory organizations and patients, are interconnected in order to considerably influence the governance results associated with the adoption of AI. As Gurzawska (2020) has installed, a multi -part approach is essential to coordinate the collaboration efforts necessary to achieve sustainable governance. This perspective underlines that without the concerted involvement of all the parties concerned, the efforts to take advantage of the AI for sustainability can vacillate due to a disalconnection of the interests, communication gaps or incomplete feedback loops.

Oluwagbade et al. (2023) Defend a life cycle governance framework for an explainable AI, stressing the need for continuous validation and an audit of biases in AI systems. This framework intrinsically requires active participation and responsibility for all stakeholders involved in the pharmacy supply chain. For example, health care providers must engage with AI systems to interpret results and make informed clinical decisions, ensuring that they are representative of the populations they serve. Likewise, regulatory organizations must engage in monitoring IA implementation, monitoring disparities and ethical considerations that may occur when AI systems are integrated into decision -making processes.

The interaction between different stakeholders is essential to identify and mitigate potential biases in AI algorithms. Al-Hourani and Weraikat (2025) argue that without an inclusive dialogue between suppliers, manufacturers and health care providers, the potential for

systemic iniquities in the provision of health care becomes pronounced. The perspective of each stakeholder informs unique information on local needs, demographic data of patients and logistical constraints, which are essential to refine AI technologies in order to promote equitable access to health resources. For example, suppliers can provide information on inventory management, which can improve AI algorithms designed to predict drug shortages or optimize stock levels. Meanwhile, manufacturers need data for market trends and patients, ensuring that production is aligned with real health care demands.

The role of regulatory organizations cannot be underestimated in this multi-party environment. Regulatory executives must not only support innovation by using AI, but also guarantee a vigilant approach to compliance and ethical practice. Stakeholders must collaborate in collaboration with regulators to shape policies that promote an environment in which AI can be deployed in a responsible manner. Without this collaboration, there is a risk that AI can exacerbate existing disparities rather than mitigating them. The need for continuous dialogue is used to align technological progress on ethical, legal and social implications surrounding the provision of health care.

Hence, the interactions between stakeholders in pharmacy supply chains integrated into the intermediary deserve a complete analysis, as they include the foundations on which sustainable governance can be carried out. The collective responsibility of these stakeholders highlights the importance of promoting relationships based on trust, transparency and mutual understanding, the essential elements to ensure that the integration of AI leads to fair and effective health results. Getting involved in this multipartite approach is not simply beneficial; It is fundamental to carry out the full potential of AI in the creation of sustainable pharmacy supply chains., The integration of artificial intelligence (AI) within the pharmaceutical supply chains is undeniably remodeling the panorama of sustainable governance, in particular through its interaction with emerging technologies and the critical role of various interested parties. Adekola, Kassem and Mbata (2022) present predictive analyzes such as a milestone of this evolution, underlining its ability to predict not only demand and optimize inventory levels, but also to improve equity in access to drugs. The ability of artificial intelligence algorithms to analyze vast data sets allows a more efficient allocation of pharmaceutical products, thus facing the disparities that often afflict health systems, especially in the underground communities. This underlines a fundamental step towards an inclusive governance model that gives priority to the equitable distribution of drugs, a critical aspect of sustainable health care.

The interaction between AI and Blockchain technology cannot be neglected. Like Damoah et al. (2021) show that the medical drones enhanced by the AI represent an innovative application that exploits the transparency and safety of the blockchain to create resilient health supply chains. The synergy between these technologies allows real -time monitoring and the verification of drug shipments, significantly minimizing the risks of counterfeit drugs and ensuring that supplies are promptly delivered to the needy areas. This illustrates a proactive approach in governance structures, in which the optimization of supply chains through technological integration contributes significantly to sustainable results.

The transition to industry 4.0 is identified by Debnath et al. (2023) as a fundamental factor in opening the way for sustainable practices in the pharmaceutical sector. The adoption of

intelligent technologies such as IoT (Internet of Things) and Machine Learning is promoting an environment in which supply chains can become increasingly reactive and adaptive. This technological convergence is not simply a trend but a vital transformation that requires solid collaboration of the interested parties. The promotion of partnerships between pharmaceutical companies, health workers, regulatory agencies and technological developers is essential to maximize the potential of these advancement technologies.

Furthermore, the importance of the collaboration of the interested parties cannot be overrated. As highlighted by Donkor, Papadopoulos and Spiegler (2024), effective communication and cooperation between all the parts involved in the pharmaceutical supply chain creates a more cooked strategy for sustainable governance. The interested parties are invited to commit themselves to shared practices that guide responsibility and transparency, the factors deemed crucial to promote trust between consumers and guarantee the fair delivery of health products. Literature suggests that when the interested parties actively participate in the governance of the supply chains, the potential for sustainable practices increases considerably, creating a shared responsibility for the results for the benefit of society in general.

In addition to the key studies, the evidence presented by Bade et al. (2024) and but et al. (2022) further strengthens the affirmation that artificial intelligence and technological convergence improve transparency, thus promoting adhesion to ethical practices and governance standards between the pharmaceutical supply chains. The common thread observed in these studies reveals an intrinsic relationship between adoption of artificial intelligence, involvement of the parties concerned and sustainable governance, placing that the actions of these interested parties affect directly on the effectiveness of artificial intelligence additions in promoting long -term sustainability in the pharmaceutical context.

Therefore, literature illustrates a clear trajectory towards a picture of the most sustainable and fair pharmaceutical supply chain, largely pushed by the integration of the AI technologies and collaborative relationships of the stakeholders, which facilitate the transition to a more sustainable governance model.

Stakeholder Theory and Sustainable Pharmacy Supply Chains

Stakeholder theory posits that organizations create value by balancing the legitimate interests of multiple parties (Freeman, 1984). In pharmacy supply chains, this includes patients and caregivers who rely on safe, affordable access; pharmacists and providers who bear professional responsibility; regulators who safeguard safety and integrity; manufacturers and distributors who must comply with quality and sustainability norms; payers who manage costs; and technology firms who design AI systems. Governance therefore requires aligning incentives so that transparency, safety, efficiency, and sustainability are not externalized.

These stakeholder expectations are evident in policy frameworks. ASEAN has pursued regulatory convergence through the ASEAN Common Technical Requirements and the ASEAN Common Technical Dossier, both of which standardize documentation on safety, efficacy, and quality across borders (ASEAN Secretariat, 2016; ASEAN Secretariat, 2021). In Malaysia, the Poisons Act 1952 regulates controlled substances, while the National Pharmaceutical Regulatory Agency has codified Good Distribution Practice standards covering quality management, audits, and cold-chain requirements (Laws of Malaysia, 1952; NPRA, 2018). The

Personal Data Protection Act 2010 establishes principles of consent, data security, and purpose limitation, which are increasingly relevant for digitalized supply chains (Department of Personal Data Protection Malaysia, 2013). Together, these instruments illustrate stakeholder commitments that AI can help operationalize.

AI Capabilities Relevant to Sustainable Governance

Artificial intelligence has demonstrated potential in improving efficiency, resilience, and sustainability across supply chains. In pharmacy contexts, AI applications include demand forecasting, inventory optimization, route planning, temperature excursion prediction, authentication, and traceability. Research in logistics has shown that machine learning improves demand forecasting accuracy, thereby reducing stock-outs and minimizing wastage (Walter et al., 2025). In pharmaceuticals, demand variability and supply shocks are significant challenges; AI forecasting tools can help align production and distribution with consumption trends.

For traceability, blockchain integrated with AI analytics enhances end-to-end visibility, deters falsified products, and automates recall processes (Ghadge et al., 2023; Sim et al., 2022). Studies report that such systems can improve recall speed and accuracy, contributing to both patient safety and regulatory compliance. Similarly, blockchain-enabled pedigrees for medicines are increasingly being tested to ensure authenticity and reduce infiltration of counterfeit drugs (Karaduman, 2025).

AI-enabled inventory management, especially in vendor-managed systems, can reduce waste, lower costs, and improve environmental outcomes by limiting overstock and reducing the carbon footprint associated with emergency shipments (Shen et al., 2024). Cold-chain monitoring using AI sensors and anomaly detection improves the reliability of temperature-sensitive products such as vaccines and biologics (Al-Hourani et al., 2025). These examples demonstrate how AI functions can be directly mapped to stakeholder concerns: regulators require transparency, pharmacists need reliable replenishment, payers demand efficiency, and patients seek safe and timely access.

Conceptual Governance Model

This study proposes a governance model built on three pillars: regulatory governance, technical governance, and operational governance.

Regulatory governance integrates ASEAN and Malaysian laws, including the Poisons Act 1952, Good Distribution Practice guidelines, and the Personal Data Protection Act 2010. It ensures that AI-enabled supply chain processes comply with established norms on safety, quality, and data protection (ASEAN Secretariat, 2016; NPRA, 2018; Department of Personal Data Protection Malaysia, 2013).

Technical governance involves validating algorithms, monitoring for bias and drift, and ensuring cybersecurity. AI systems must be explainable and auditable to satisfy both regulators and stakeholders, reflecting the governance need for transparency in algorithmic decisions (Ghadge et al., 2023).

Operational governance focuses on measurable performance indicators such as stock-out rates, temperature deviations, waste, and carbon emissions. These metrics are reported to

stakeholders to ensure accountability. Malaysia's Good Distribution Practice provides specific anchors for this governance, including vehicle temperature mapping, documented cold-chain handovers, and corrective actions (NPRA, 2018). By aligning these requirements with AI monitoring and reporting, the framework establishes patient trust and system accountability.

Research Methodology

This study employs a conceptual and theory-driven methodological approach to develop a governance framework for the integration of artificial intelligence (AI) into pharmacy supply chains. The paper does not involve empirical testing or data collection. Instead, it relies on synthesizing theoretical insights, regulatory frameworks, and cross-disciplinary literature to construct a normative model of sustainable governance, particularly suited to the context of Malaysia and the ASEAN region.

The foundation of the framework is based on stakeholder theory, which provides a lens for identifying and analyzing the roles, responsibilities, and expectations of diverse actors involved in pharmacy supply chains. These stakeholders include regulators, manufacturers, pharmacists, patients, technology providers, and payers. Stakeholder theory also informs how governance arrangements should align AI capabilities with public interest, professional accountability, and regulatory compliance in healthcare delivery.

The conceptual model is further shaped through a review of existing literature across several fields, including AI in pharmaceutical logistics, digital governance, sustainable supply chain management, and healthcare policy. Studies on predictive analytics, blockchain-enabled traceability, inventory optimization, and algorithmic governance inform the technical and institutional components of the model. Sources such as Sim et al., Shen et al., and Oluwagbade et al. provide practical illustrations of how AI is currently being applied and where governance gaps may arise.

In addition to the theoretical foundation, the study integrates key policy instruments from Malaysia and ASEAN. These include the Poisons Act 1952, the Good Distribution Practice guidelines issued by the National Pharmaceutical Regulatory Agency, and the Personal Data Protection Act 2010. Regional standards such as the ASEAN Common Technical Requirements and Common Technical Dossier are also considered. The inclusion of these legal and policy frameworks ensures that the proposed model is normatively grounded and operationally feasible across different regulatory contexts.

The final conceptual model is constructed through a mapping of stakeholder expectations to specific AI functions. These expectations include transparency, safety, data privacy, cost efficiency, and equitable access, while AI functions encompass demand forecasting, anomaly detection, cold-chain monitoring, and traceability. The model is organized around three governance domains: regulatory governance, which ensures compliance with legal standards and ethical norms; technical governance, which relates to the validation and transparency of AI systems; and operational governance, which focuses on measurable performance indicators and continuous improvement.

As a conceptual paper, this methodology supports the development of a structured governance model that can be refined and empirically tested in future studies. The model is

intended to serve both as a theoretical contribution to the literature on AI and supply chain sustainability and as a practical reference for policymakers, regulators, and healthcare stakeholders pursuing digital transformation in pharmaceutical governance.

Discussion

Applying stakeholder theory reveals that sustainable pharmacy supply chain governance requires equitable allocation of responsibilities and benefits. Without alignment, stakeholders may under-invest in data quality or withhold information, which undermines reliability. For example, if cold-chain monitoring data remain siloed with distributors, pharmacists cannot act proactively to prevent excursions. Conversely, if such telemetry is shared transparently with automated alerts, both parties can act to reduce risks, improving outcomes for patients and regulators alike (Shen et al., 2024).

Similarly, blockchain-based drug pedigrees provide incentives for manufacturers and distributors to comply with standards. If purchasing bodies and regulators mandate such systems, non-compliance becomes less attractive, reducing counterfeit infiltration (Sim et al., 2022). Stakeholder theory underscores that trust, fairness, and accountability are essential in these arrangements, not only technical efficiency.

Applying stakeholder theory reveals that sustainable pharmacy supply chain governance requires equitable allocation of responsibilities and benefits. Without alignment, stakeholders may under-invest in data quality or withhold information, which undermines reliability. For example, if cold-chain monitoring data remain siloed with distributors, pharmacists cannot act proactively to prevent excursions. Conversely, if such telemetry is shared transparently with automated alerts, both parties can act to reduce risks, improving outcomes for patients and regulators alike.

Similarly, blockchain-based drug pedigrees provide incentives for manufacturers and distributors to comply with standards. If purchasing bodies and regulators mandate such systems, non-compliance becomes less attractive, reducing counterfeit infiltration. Stakeholder theory underscores that trust, fairness, and accountability are essential in these arrangements, not only technical efficiency.

In practice, integrating AI across pharmacy supply chains demands that stakeholder roles are not only defined, but also institutionally embedded into governance frameworks. For instance, manufacturers and distributors must be incentivized to share real-time supply data without fear of misuse. Regulators must develop algorithm-validation protocols that are transparent, fair, and interoperable across borders. Pharmacists and clinicians must be trained to interpret AI-driven alerts ethically, particularly when decisions involve patient safety or medication substitutions.

The discussion also highlights that sustainability in supply chains extends beyond environmental considerations to include social equity and institutional resilience. In regions where access to pharmacies is uneven, such as in Malaysia's rural districts with ratios as low as 1:61,707 residents per pharmacy, AI can improve access through mobile-enabled last-mile delivery and dynamic restocking systems. However, without robust governance structures, these innovations may only benefit urban populations, further widening health inequities.

Therefore, equitable access must be explicitly built into AI deployment frameworks through inclusive policy design.

Moreover, the trust deficit that often accompanies AI deployment in healthcare must be addressed through explainability and stakeholder participation. Patients and civil society actors should have visibility into how AI-driven decisions are made, particularly in the context of risk scoring, medication substitution, or resource allocation. Ensuring patient trust is critical in environments where falsified products are prevalent, and confidence in medicine quality is fragile. AI tools that explain why certain drugs are flagged or removed from the supply chain build transparency and legitimacy.

Cross-sectoral collaboration is also crucial. Technology firms must not operate in isolation from public health priorities. Governance structures must enable regular dialogue between AI developers and public health regulators to ensure that system objectives are aligned with national safety and access goals. A single-point compliance interface involving all actors may facilitate joint oversight and risk mitigation, reducing duplicated efforts and allowing interoperability.

Finally, the ASEAN context offers a valuable proving ground for region-wide governance harmonization. With diverse digital health capacities and regulatory maturity levels, ASEAN members must coordinate AI-enabled supply chain norms through consensus. ASEAN's commitment to regulatory convergence through the Common Technical Requirements and digital health adoption guidelines provides a foundation. However, this must be accompanied by capacity building, especially in less digitally advanced economies, to ensure that governance is not only technically sound but also socially inclusive and enforceable.

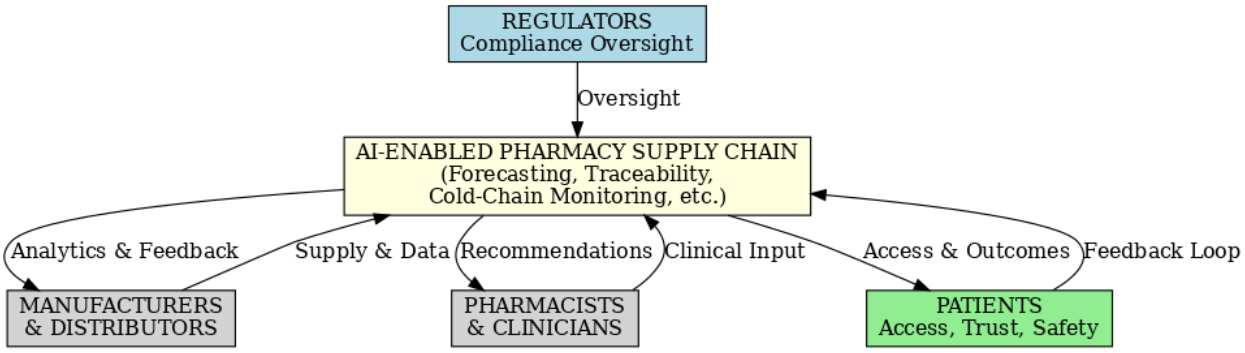

Figure 1: Stakeholder-Governed AI Integration Framework for Sustainable Pharmacy Supply Chains

Figure 1 illustrates the dynamic relationship between key stakeholder groups and the AI-enabled pharmacy supply chain system. At the core is the AI-integrated supply chain responsible for forecasting, inventory control, real-time traceability, and cold-chain monitoring. Regulators interact at the top, providing oversight and governance. Manufacturers and distributors supply real-time data, while pharmacists and clinicians engage with AI outputs in decision-making. Patients are the end beneficiaries, whose access, safety, and trust reflect the system's performance. Feedback flows continuously across all entities to ensure ethical, sustainable, and transparent operations. The diagram

operationalizes stakeholder theory by showing aligned roles, responsibilities, and feedback loops for sustainable governance.

Conclusion

Sustainable governance of pharmacy supply chains is a multi-stakeholder challenge requiring both robust technology and effective institutional design. A stakeholder-theory perspective clarifies how AI functions, when embedded in governance, can improve reliability, traceability, efficiency, and environmental performance. Global evidence on medication errors and counterfeit prevalence highlights the urgency of reform, while Malaysia's regulatory framework and ASEAN's harmonization efforts provide fertile ground for implementation. Aligning stakeholder expectations with AI-enabled governance offers a pathway to improved patient safety, equitable access, and trust. Future studies should empirically test the model to inform policy and practice across Malaysia and the ASEAN region.

Policymakers in Malaysia can integrate AI-enabled oversight into existing frameworks such as NPRA's Good Distribution Practice, making AI tools part of compliance checks. Regulators should extend requirements to cover algorithm validation and transparency, similar to existing documentation obligations for temperature control (NPRA, 2018). Healthcare purchasers can include sustainability and traceability requirements in contracts, incentivizing vendors to adopt AI solutions.

Managers should emphasize data readiness, cross-functional collaboration, and staff training. For pharmacists and clinicians, explainability is critical, as professional accountability cannot be delegated to machines. At the regional level, ASEAN can promote harmonized AI standards for traceability and supply chain data sharing, aligning digital transformation with cross-border pharmaceutical flows (ASEAN-Japan Centre, 2024).

This paper is conceptual and does not provide empirical testing. Variability in regulatory capacity and infrastructure across ASEAN may limit generalizability. AI adoption also faces risks related to cost, interoperability, and cybersecurity, which could delay implementation. Future research should test the proposed model empirically in both Malaysia and other ASEAN countries.

Acknowledgement

The authors gratefully acknowledge the support of the Accounting Research Institute (HICoE), Universiti Teknologi MARA, and the Ministry of Higher Education Malaysia for facilitating this research

References

Adekola, A. D., Kassem, R. G., & Mbata, A. O. (2022). Convergence of AI, blockchain, and pharmacoeconomics in building adaptive pharmaceutical supply chains: A novel paradigm shift for equitable global drug access. Int J Sci Res Updates, 4(1), 356-74.

Al-Hourani, S., & Weraikat, D. (2025). A Systematic Review of Artificial Intelligence (AI) and Machine Learning (ML) in Pharmaceutical Supply Chain (PSC) Resilience: Current Trends and Future Directions. Sustainability, 17(14), 6591.

Al-Hourani, S., Mudabber, A., & Ahmed, A. (2025). A systematic review of artificial intelligence and sustainable supply chains: Evidence, gaps and future agenda. *Sustainability, 17*(14), 6591

ASEAN Secretariat. (2016). *ASEAN Common Technical Dossier (ACTD): Table of contents and organization*.

ASEAN Secretariat. (2021). *ASEAN Common Technical Requirements (ACTR)*.

ASEAN-Japan Centre. (2024). *Assessing digital health adoption in ASEAN*.

Bade, C., Olsacher, A., Boehme, P., Truebel, H., Bürger, L., & Fehring, L. (2024). Sustainability in the pharmaceutical industry—An assessment of sustainability maturity and effects of sustainability measure implementation on supply chain security. Corporate Social Responsibility and Environmental Management, 31(1), 224-242.

Bukhari, N., Dawoud, D., & Mariam, A. (2021). Geospatial analysis of distribution of community pharmacies and characteristics of the populations they serve: A case study of Malaysia. *Journal of Pharmaceutical Policy and Practice, 14*(74).

Damoah, I. S., Ayakwah, A., & Tingbani, I. (2021). Artificial intelligence (AI)-enhanced medical drones in the healthcare supply chain (HSC) for sustainability development: A case study. Journal of Cleaner Production, 328, 129598.

Debnath, B., Shakur, M. S., Bari, A. M., Saha, J., Porna, W. A., Mishu, M. J., ... & Rahman, M. A. (2023). Assessing the critical success factors for implementing industry 4.0 in the pharmaceutical industry: implications for supply chain sustainability in emerging economies. Plos one, 18(6), e0287149.

Department of Personal Data Protection Malaysia. (2013). *Personal Data Protection Act 2010 (Act 709)*. Government of Malaysia.

Donkor, F., Papadopoulos, T., & Spiegler, V. (2024). Supply chain integration and supply chain sustainability relationship: A qualitative analysis of the UK and Ghana pharmaceutical industry. Production Planning & Control, 35(6), 535-558.

Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman.

Ghadge, A., Tsanis, K., Tiwari, A., Kumar, M., & Chakraborty, A. (2023). Blockchain implementation in pharmaceutical supply chains: A review and conceptual framework. *International Journal of Production Research, 61*(24), 8451–8476.

GSMA. (2023). *The mobile economy Asia Pacific 2023*. GSMA.

Gurzawska, A. (2020). Towards responsible and sustainable supply chains–innovation, multi-stakeholder approach and governance. Philosophy of Management, 19(3), 267-295.

Hao, X., & Demir, E. (2024). Artificial intelligence in supply chain decision-making: an environmental, social, and governance triggering and technological inhibiting protocol. Journal of Modelling in Management, 19(2), 605-629.

Ismail, A., Gan, Y. N., & Ahmad, N. (2020). Factors associated with patient satisfaction towards pharmacy services among out-patients attending public health clinics: Questionnaire development and its application. *PLOS ONE, 15*(11), e0241082.

Karaduman, Ö. (2025). Blockchain-enabled supply chain management: A review of applications, frameworks and limitations. *Applied Sciences, 15*(9), 5168.

Laws of Malaysia. (1952). *Poisons Act 1952 (Act 366, Revised 1989)*. Government of Malaysia.

Laws of Malaysia. (1952). *Poisons Act 1952 (Act 366, Revised 1989)*. Government of

Ma, J. Y., Shi, L., & Kang, T. W. (2022). The effect of digital transformation on the pharmaceutical sustainable supply chain performance: The mediating role of information sharing and traceability using structural equation modeling. Sustainability, 15(1), 649.

Ministry of Health Malaysia. (2025). *Guideline on online healthcare services*. Ministry of Health Malaysia.

National Pharmaceutical Regulatory Agency (NPRA). (2018). *Guideline on Good Distribution Practice (3rd ed.)*. Ministry of Health Malaysia.

National Pharmaceutical Regulatory Agency. (2018). *Guideline on Good Distribution Practice (3rd ed.)*. Ministry of Health Malaysia.

Oluwagbade, E., Vincent, A., Oluwole, O., & Animasahun, B. (2023). Lifecycle governance for explainable AI in pharmaceutical supply chains: a framework for continuous validation, bias auditing, and equitable healthcare delivery. Int J Eng Technol Res Manag, 7(11), 54.

Oluwole, O., Emmanuel, E., Ogbuagu, O. O., Alemede, V., & Adefolaju, I. (2024). Pharmaceutical supply chain optimization through predictive analytics and value-based healthcare economics frameworks.

Shashi, M. (2023). Sustainable digitalization in pharmaceutical supply chains using theory of constraints: A qualitative study. Sustainability, 15(11), 8752.

Shen, J., Zhang, Q., Ma, H., & Li, H. (2024). Management of drug supply-chain information based on AI and vendor-managed inventory. *BMC Medical Informatics and Decision Making, 24*(51).

Sim, C., Kuo, T., & Chen, Y. (2022). Improving end-to-end traceability and pharmaceutical supply chains through blockchain. *Frontiers in Blockchain, 5*, 1033702.

Walter, A., Roth, A., & Khalil, S. (2025). Application of artificial intelligence in demand planning for supply chains: A systematic review. *The International Journal of Logistics Management, 36*(3), 672–699.

World Health Organization. (2017a, March 29). WHO launches global effort to halve medication-related errors in five years. World Health Organization.

World Health Organization. (2017b, November 28). 1 in 10 medical products in developing countries is substandard or falsified. World Health Organization.