



Artificial Intelligence-Enabled Microbiology in Supply Chain and Transport Management: Evidence from Nigerian Teaching Hospitals

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Abstract

Original Research Article

Artificial Intelligence (AI) has emerged as a transformative tool in microbiology, enabling predictive diagnostics and operational optimisation in healthcare supply chains. This study investigates the influence of AI-enabled microbiology on supply chain reliability, transport performance, cold-chain integrity, and safety compliance across six Nigerian teaching hospitals representing all geopolitical zones. Using a quantitative design, data were collected from 502 respondents, comprising laboratory scientists, microbiologists, and supply chain and transport personnel. Analyses employing descriptive statistics, correlation, and multiple regression revealed that AI adoption significantly enhances all measured outcomes ($r = 0.64-0.77$, $p < 0.01$), explaining 48–56% of the variance. AI’s impact was particularly pronounced in predictive pathogen detection, real-time transport monitoring, and enhanced regulatory compliance. Challenges such as fragmented infrastructure and uneven human capacity moderated effectiveness. The findings indicate that AI-integrated microbiology is a strategic enabler of resilient healthcare supply chains in Nigeria, with implications for policy and institutional investment.

Keywords: Artificial Intelligence, Microbiology, Supply Chain Management, Transport Management, Cold Chain, Nigerian Teaching Hospitals.

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Introduction

Healthcare supply chains in Nigeria face persistent operational challenges, particularly in transporting biological materials such as vaccines, blood products, and diagnostic

reagents. These materials are highly sensitive to delays, temperature fluctuations, and handling errors, which can compromise patient outcomes and increase operational costs (Adeyemi, Akinola, & Bello, 2024; Musa & Akande, 2023). Teaching hospitals, which serve as both



diagnostic and distribution hubs, often encounter logistical inefficiencies due to fragmented transport systems, manual laboratory processes, and limited integration between microbiological laboratories and supply chain operations. Consequently, there is a critical need for innovative technologies that enhance reliability, accuracy, and timeliness in healthcare delivery.

Artificial Intelligence (AI) has emerged as a transformative tool capable of addressing these challenges. In microbiology, AI facilitates predictive pathogen detection, anomaly identification, and workflow optimisation, allowing laboratories to convert complex biological data into actionable insights (Li, Wang, & Xu, 2023; Zhou, Zhang, & Li, 2022). By integrating AI outputs with supply chain management, hospitals can anticipate stock shortages, optimise delivery routes, and maintain cold-chain integrity. Nigerian teaching hospitals such as University College Hospital, Ibadan, and University of Benin Teaching Hospital have begun adopting AI-enabled laboratory systems, showing measurable improvements in sample traceability, diagnostic turnaround, and transport scheduling (Afolabi & Chukwu, 2024; Okoye, Eze, & Nnamani, 2025).

Transport management is a critical interface between laboratory insights and operational performance. AI facilitates predictive scheduling, sensor-based monitoring, and real-time decision-making, which ensure that temperature-sensitive biological materials remain viable during transit (Nguyen & Tran, 2023; Al-Mashaqbeh & Qatawneh, 2021). The University of Maiduguri Teaching Hospital and University of Abuja Teaching Hospital, Gwagwalada, exemplify how AI-driven transport management can mitigate risks associated with infrastructural limitations, climatic variability, and long-distance distribution. These innovations allow hospitals to optimise delivery routes, reduce delays, and maintain compliance with regulatory standards.

Despite these benefits, the adoption of AI in Nigerian healthcare is uneven, constrained by systemic challenges such as insufficient digital infrastructure, fragmented IT systems, and limited human capacity (Adebayo, Nwafor, & Oladipo, 2023; Johnson, Bello, & Akpan,

2026). Hospitals in semi-urban areas often face more pronounced difficulties in integrating AI due to inconsistent electricity supply, limited access to sensors and monitoring devices, and shortages of trained personnel. This highlights the importance of contextualised strategies that combine technological innovation with capacity building and infrastructure development to maximise AI's impact on supply chain and transport operations.

This study therefore investigates the role of AI-enabled microbiology in improving supply chain reliability, transport performance, cold-chain integrity, and safety compliance across six Nigerian teaching hospitals representing all geopolitical zones. By examining 502 respondents, including laboratory scientists, microbiologists, supply chain officers, and transport managers, the study seeks to provide empirical evidence on how AI can be strategically leveraged to optimise hospital logistics. Integrating Nigerian case illustrations ensures contextual relevance, while the study's quantitative approach enables robust analysis of the operational impact of AI-enabled microbiology on healthcare supply chain and transport management.

Literature Review

2.1 AI in Microbiology and Predictive Analytics

Artificial Intelligence (AI) has transformed microbiology by enabling predictive analytics that convert complex biological data into actionable insights for healthcare decision-making (Li, Wang, & Xu, 2023; Zhou, Zhang, & Li, 2022). Predictive analytics uses machine learning algorithms to detect patterns in microbial growth, disease prevalence, and pathogen resistance, allowing hospitals to anticipate outbreaks and optimise resource allocation. Unlike conventional laboratory approaches, which rely on reactive diagnostics, AI-driven predictive microbiology allows for proactive intervention, reducing diagnostic delays and improving patient outcomes (Wang, Liu, & Chen, 2025).

In the Nigerian context, teaching hospitals are increasingly leveraging AI to enhance microbiological diagnostics and integrate these outputs into supply chain management. For example, University College Hospital, Ibadan, employs AI-powered diagnostic tools that predict potential contamination risks in biological samples, enabling staff to adjust handling and transport protocols preemptively (Afolabi&Chukwu, 2024). Similarly, University of Benin Teaching Hospital uses AI algorithms to forecast laboratory reagent consumption, optimise inventory management, and reduce stockouts, demonstrating the operational value of predictive analytics in resource-constrained environments (Okoye, Eze, &Nnamani, 2025).

Predictive analytics in microbiology is particularly critical for managing cold-chain logistics. AI models can forecast temperature excursions and degradation risks for biological samples during transport, enabling preemptive corrective actions (Nguyen & Tran, 2023). University of Abuja Teaching Hospital, Gwagwalada, has integrated AI monitoring into its vaccine distribution process, using predictive alerts to reroute shipments in response to environmental risks. This reduces wastage, ensures regulatory compliance, and maintains the efficacy of temperature-sensitive materials.

The integration of AI in microbiology also facilitates real-time decision-making, combining laboratory insights with transport and supply chain data. This enables hospitals to coordinate across departments, improve sample traceability, and optimise delivery schedules (Dubey et al., 2022; Ibrahim & Musa, 2025). The predictive power of AI ensures that logistical decisions are informed by actual laboratory data rather than assumptions, which is particularly relevant in Nigeria where infrastructure and transport challenges can disrupt the timely delivery of biological materials.

However, despite these advances, adoption remains uneven across Nigeria due to limited technical capacity, fragmented IT systems, and resource constraints (Adebayo, Nwafor, &Oladipo, 2023; Johnson, Bello, &Akpan, 2026). To realise the full potential of AI-driven predictive analytics, hospitals must invest in training, infrastructure, and cross-departmental

integration. When effectively implemented, AI predictive tools in microbiology can significantly enhance the operational efficiency, safety, and reliability of healthcare supply chains, especially in contexts characterised by logistical complexity and infrastructural variability.

2.2 AI in Supply Chain and Transport Management

Artificial Intelligence (AI) has emerged as a critical enabler in supply chain and transport management, particularly within complex healthcare systems where timely delivery of biological materials is paramount. AI applications in supply chains include predictive demand forecasting, route optimisation, real-time tracking, and anomaly detection, which collectively enhance efficiency, reduce operational costs, and improve regulatory compliance (Nguyen & Tran, 2023; Dubey et al., 2022). Unlike conventional management approaches, AI enables dynamic, data-driven decision-making, allowing healthcare facilities to pre-empt disruptions and respond proactively to logistical challenges.

In the Nigerian healthcare context, teaching hospitals have begun integrating AI into their supply chain and transport operations with demonstrable impact. For instance, University of Abuja Teaching Hospital, Gwagwalada, employs AI algorithms to predict delivery times and detect potential delays in vaccine distribution. By combining laboratory outputs with transportation data, the hospital can dynamically reroute shipments, ensuring timely delivery while preserving cold-chain integrity (Ibrahim & Musa, 2025). Similarly, University of Benin Teaching Hospital leverages AI-enabled monitoring to maintain real-time oversight of reagent and sample transport, reducing spoilage and minimising the risk of compromised diagnostic accuracy (Okoye, Eze, &Nnamani, 2025).

Transport management in healthcare supply chains is particularly sensitive to environmental and infrastructural constraints. AI tools facilitate predictive maintenance of transport vehicles, environmental monitoring during transit, and

route optimisation considering traffic and road conditions (Li, Wang, & Xu, 2023). For example, northern hospitals such as University of Maiduguri Teaching Hospital face challenges related to road accessibility and climatic variability. AI-driven predictive models allow these institutions to schedule transport during optimal windows, monitor temperature-sensitive shipments, and alert staff to potential hazards, demonstrating the value of context-specific AI applications in supply chain resilience (Afolabi & Chukwu, 2024).

Furthermore, AI integration supports compliance with regulatory and safety standards, an essential aspect of healthcare supply chain management. Automated monitoring and predictive alerts ensure adherence to cold-chain protocols and prevent deviations that could compromise sample integrity (Al-Mashaqbeh & Qatawneh, 2021). In practice, hospitals employing AI systems achieve higher compliance rates, which enhances trust in diagnostic outcomes and aligns with national health regulations (Adebayo, Nwafor, & Oladipo, 2023).

Despite these advances, widespread adoption of AI in Nigerian healthcare supply chains remains constrained by systemic issues, including fragmented IT infrastructure, limited trained personnel, and inconsistent policy frameworks (Johnson, Bello, & Akpan, 2026). Addressing these barriers requires strategic investment in digital infrastructure, capacity-building programmes for laboratory and logistics staff, and cross-departmental integration of AI systems. When effectively implemented, AI-driven supply chain and transport management not only enhances operational efficiency but also strengthens healthcare system resilience, particularly in contexts characterised by infrastructural variability and logistical complexity.

2.3 Contextual Challenges in Nigeria

Despite the transformative potential of AI in microbiology and supply chain management, Nigerian healthcare institutions face significant contextual challenges that limit adoption and effectiveness. Infrastructure remains a primary constraint. Many hospitals contend with

unreliable electricity supply, limited internet connectivity, and fragmented laboratory information systems, all of which impede the continuous operation of AI-enabled tools (Adebayo, Nwafor, & Oladipo, 2023; Johnson, Bello, & Akpan, 2026). For instance, although University of Abuja Teaching Hospital, Gwagwalada, has implemented AI-based transport monitoring, intermittent power outages occasionally disrupt data collection, delaying predictive alerts and reducing operational efficiency.

Human capacity represents another critical challenge. AI adoption requires personnel with technical expertise in machine learning, data analytics, and laboratory informatics (Okoye, Eze, & Nnamani, 2025). In many Nigerian teaching hospitals, such as University of Maiduguri Teaching Hospital, shortages of trained laboratory and logistics staff constrain the integration of AI outputs into routine operations. These gaps result in underutilisation of AI tools and reduce the accuracy of predictive analytics, undermining potential gains in supply chain and transport performance.

Resource limitations further constrain AI integration. High acquisition and maintenance costs of AI systems, including sensors, software licenses, and data storage solutions, are often prohibitive for hospitals operating under constrained budgets (Afolabi & Chukwu, 2024). Even where systems are deployed, limited funding for continuous training and system upgrades compromises long-term sustainability. Consequently, hospitals may implement AI partially, using only selected functionalities rather than fully integrated predictive and transport solutions.

Geographical and environmental factors also exacerbate logistical challenges. Nigeria's diverse terrain, ranging from flood-prone southern regions to arid northern areas, complicates the transport of biological materials, particularly those requiring strict cold-chain maintenance (Nguyen & Tran, 2023). Teaching hospitals such as University of Benin Teaching Hospital and Ahmadu Bello University Teaching Hospital, Zaria, must contend with these environmental constraints while ensuring that AI-enabled predictive monitoring maintains

sample integrity. Delays caused by poor road networks, traffic congestion, or adverse weather can diminish the operational advantages of AI if not accounted for in system design.

Policy and regulatory frameworks present an additional challenge. While Nigeria has developed policies for digital health and laboratory management, enforcement is uneven, and interoperability between AI systems and national regulatory databases is limited (Adebayo et al., 2023). Hospitals often face uncertainty regarding compliance with data standards, patient privacy, and reporting requirements, which can hinder AI adoption and integration into supply chain and transport management. Addressing these challenges requires coordinated investment in infrastructure, human capacity, and governance to create an environment in which AI can deliver its full potential in Nigerian healthcare.

The conceptual framework underpinning this study posits that AI-enabled microbiology (AI_MICRO) serves as a strategic enabler for enhanced supply chain and transport management in Nigerian teaching hospitals. AI_MICRO encompasses predictive analytics, real-time laboratory monitoring, and anomaly detection, which together generate actionable intelligence for operational decision-making (Li, Wang, & Xu, 2023; Zhou, Zhang, & Li, 2022). This intelligence informs four interrelated outcome domains: Supply Chain Reliability (SC_REL), Transport Performance (TRANS_PERF), Cold-Chain Integrity (COLD_INT), and Safety Compliance (SAFE_COMP).

- Supply Chain Reliability (SC_REL) reflects the ability of hospitals to maintain consistent stock levels of biological materials, minimise stockouts, and ensure timely replenishment (Okoye, Eze, & Nnamani, 2025). For example, University of Benin Teaching Hospital employs AI forecasts to anticipate reagent demand and avoid disruptions in diagnostic workflows, demonstrating the operational relevance of predictive microbiology to supply chain stability.

- Transport Performance (TRANS_PERF) captures the efficiency of sample and reagent delivery, including adherence to schedules, route optimisation, and minimisation of delays (Nguyen & Tran, 2023). In northern hospitals such as University of Maiduguri Teaching Hospital and University of Abuja Teaching Hospital, Gwagwalada, AI-driven transport analytics enable proactive adjustments to schedules, mitigating the impact of poor road networks and adverse climatic conditions.
- Cold-Chain Integrity (COLD_INT) measures the maintenance of optimal environmental conditions during transport and storage of biological materials, ensuring sample viability and therapeutic efficacy (Al-Mashaqbeh & Qatawneh, 2021). Predictive monitoring systems in teaching hospitals alert staff to deviations in temperature or humidity, allowing corrective interventions before spoilage occurs.
- Safety Compliance (SAFE_COMP) refers to adherence to national and institutional regulatory standards in laboratory handling, storage, and transport of microbiological materials (Adebayo, Nwafor, & Oladipo, 2023). AI systems enable automated reporting and auditing, reducing human error and enhancing accountability, as observed in University College Hospital, Ibadan.

The conceptual model integrates AI_MICRO as the independent variable influencing the four dependent variables (SC_REL, TRANS_PERF, COLD_INT, SAFE_COMP), with contextual factors in Nigeria, such as infrastructure, human capacity, environmental variability, and policy enforcement, acting as moderating variables. This framework recognises that the impact of AI is contingent upon contextual realities, reflecting both the technological potential and operational limitations of Nigerian teaching hospitals.

By linking predictive microbiology to supply chain and transport outcomes, this framework

allows for empirical testing of AI's operational value. It emphasises that AI adoption is not merely a technological upgrade but a strategic intervention that requires integration across laboratory, logistics, and policy domains to achieve tangible improvements in healthcare delivery.

3. Methodology

3.1 Research Design

This study employed a quantitative, cross-sectional survey design, appropriate for examining the relationship between AI-enabled microbiology and supply chain and transport management in Nigerian teaching hospitals. Quantitative methods enable systematic measurement and statistical analysis of variables, ensuring objectivity, replicability, and generalisability of findings (Creswell & Creswell, 2022). A cross-sectional design was selected because it captures a snapshot of AI adoption, operational performance, and logistical outcomes across multiple hospitals simultaneously, facilitating comparisons across regions and institutional contexts.

3.2 Population and Study Sites

The study population consisted of laboratory scientists, microbiologists, supply chain managers, and transport officers employed in six teaching hospitals representing Nigeria's six geopolitical zones:

1. **University of Abuja Teaching Hospital, Gwagwalada** – North-Central
2. **University of Maiduguri Teaching Hospital** – North-East
3. **Ahmadu Bello University Teaching Hospital, Zaria** – North-West
4. **University College Hospital, Ibadan** – South-West
5. **University of Benin Teaching Hospital** – South-South
6. **University of Nigeria Teaching Hospital, Enugu** – South-East

These institutions were selected based on their active engagement with AI-enabled laboratory or transport systems, representing diverse operational, infrastructural, and environmental contexts within Nigeria (Afolabi&Chukwu, 2024; Ibrahim & Musa, 2025). The total population of eligible staff across these hospitals was estimated at 800 individuals.

3.3 Sample Size and Sampling Technique

A total of 502 respondents were purposively sampled to ensure representation across the six hospitals, capturing staff directly involved in laboratory operations, supply chain management, and transport logistics. The purposive sampling technique was chosen due to the specialised knowledge required to respond meaningfully to AI and supply chain-related questions (Etikan, Musa, & Alkassim, 2021). This sample size exceeds the minimum threshold for quantitative studies of this scale, enhancing the robustness and reliability of statistical analyses.

3.4 Instrumentation

Data were collected using a structured questionnaire, developed based on the conceptual framework and operationalisation of variables. The instrument consisted of five sections:

1. **Demographics:** Age, gender, educational background, professional role, and years of experience.
2. **AI-enabled Microbiology (AI_MICRO):** 10 items measuring predictive analytics usage, laboratory monitoring, and anomaly detection (Likert scale: 1 = Strongly Disagree to 5 = Strongly Agree).
3. **Supply Chain Reliability (SC_REL):** 6 items assessing stock management, replenishment efficiency, and operational continuity.
4. **Transport Performance (TRANS_PERF):** 6 items on route optimisation, delivery timeliness, and vehicle utilisation.

5. Cold-Chain Integrity (COLD_INT) and Safety Compliance (SAFE_COMP): 6 items combined, measuring adherence to temperature standards, regulatory compliance, and incident reporting.

The questionnaire underwent face and content validation by experts in AI, microbiology, and healthcare logistics. A pilot study involving 30 respondents from a non-sampled teaching hospital (FMC Lokoja) was conducted to assess reliability. Cronbach’s alpha coefficients exceeded 0.80 for all constructs, indicating strong internal consistency (Nunnally & Bernstein, 1994).

3.5 Data Collection Procedure

Ethical approval was obtained from each participating hospital’s Research Ethics Committee, ensuring compliance with national research standards and participant confidentiality. Respondents were approached in person and via institutional email, with informed consent obtained prior to participation. Questionnaires were self-administered, allowing respondents to provide data based on their direct

operational experience with AI-enabled laboratory and transport systems. Data collection occurred over a six-week period, ensuring adequate time for response and follow-up.

3.6 Data Analysis

Data were coded and analysed using SPSS Version 29. Descriptive statistics (mean, standard deviation, frequencies) summarised demographic profiles and operational patterns. Inferential statistics, including Pearson correlation and multiple regression analysis, were employed to examine relationships between AI_MICRO (independent variable) and the dependent variables (SC_REL, TRANS_PERF, COLD_INT, SAFE_COMP). The level of significance was set at $p < 0.05$.

Additionally, moderation analysis was conducted to assess the influence of contextual factors (infrastructure, human capacity, policy environment) on the relationship between AI adoption and operational outcomes. These analyses allowed for the identification of both direct and indirect effects, providing a robust understanding of AI’s operational impact within Nigerian teaching hospitals.

4. Results

4.1 Demographic Characteristics of Respondents

Table 1: Demographic Profile of Respondents (N = 502)

Demographic Variable	Category	Frequency (f)	Percentage (%)
Gender	Male	261	52
	Female	241	48
Age (years)	20–29	102	20
	30–45	306	61
	46–60	94	19
Educational Qualification	Diploma/Professional Certification	211	42
	First Degree or Higher	291	58
Professional Role	Laboratory Scientist	176	35
	Microbiologist	126	25

	Supply Chain Officer	100	20
	Transport/Logistics Officer	100	20
Years of Experience	1–5	78	16
	6–10	284	57
	11+	140	27

Interpretation of Demographic Characteristics

- Gender Distribution:** The sample shows a relatively balanced gender representation (52% male, 48% female), reflecting equitable participation of both male and female staff in laboratory and logistics operations across Nigerian teaching hospitals. This balance supports generalisability and reduces potential gender bias in perceptions of AI adoption.
- Age Profile:** The majority of respondents (61%) are aged 30–45 years, indicating a workforce in the prime of their professional career with sufficient operational experience to provide informed responses on AI-enabled systems. A smaller proportion (19%) are above 46 years, reflecting the continued engagement of experienced senior personnel in supply chain and laboratory oversight.
- Educational Qualifications:** More than half of the respondents (58%) hold a first degree or higher, suggesting a relatively high level of formal education, which is critical for understanding, implementing, and interacting with AI-enabled laboratory and transport systems. The remaining 42% with diplomas or professional certifications indicate practical expertise, ensuring that operational perspectives are captured alongside academic knowledge.
- Professional Roles:** Laboratory scientists constitute the largest professional group (35%), followed by microbiologists (25%), supply chain officers (20%), and transport/logistics officers (20%). This distribution reflects the multi-disciplinary nature of AI integration in teaching hospitals, where predictive analytics, laboratory operations, and transport management converge.
- Years of Experience:** Most respondents (57%) have 6–10 years of professional experience, indicating substantial familiarity with hospital operations and supply chain processes. The combination of mid-career and senior personnel ensures that the dataset incorporates both operational knowledge and strategic oversight, enhancing the reliability of findings on AI adoption and its impact on logistics.

4.2 Descriptive Analysis of Variables

Table 1 summarises the descriptive statistics for all key variables: AI-enabled Microbiology (AI_MICRO), Supply Chain Reliability (SC_REL), Transport Performance (TRANS_PERF), Cold-Chain Integrity (COLD_INT), and Safety Compliance (SAFE_COMP).

Table 1: Descriptive Statistics of Study Variables

Variable	Mean	SD	Min	Max
AI_MICRO	4.12	0.58	2.0	5.0
SC_REL	3.96	0.62	2.0	5.0
TRANS_PERF	3.89	0.65	1.5	5.0
COLD_INT	4.05	0.60	2.0	5.0
SAFE_COMP	4.01	0.57	2.0	5.0

The results indicate that respondents perceived moderate-to-high adoption of AI in microbiology (M = 4.12, SD = 0.58), suggesting that predictive analytics, laboratory monitoring, and anomaly detection are actively used in the sampled teaching hospitals. Supply Chain Reliability (M = 3.96) and Transport Performance (M = 3.89) were also moderately high, reflecting tangible operational improvements attributable to AI-enabled interventions. Cold-Chain Integrity and Safety Compliance showed similarly high mean values

(M ≈ 4.0), highlighting AI’s contribution to adherence to temperature standards and regulatory protocols.

4.3 Correlation Analysis

Pearson correlation analysis was conducted to examine the relationships between AI_MICRO and the dependent variables (SC_REL, TRANS_PERF, COLD_INT, SAFE_COMP).

Table 2: Pearson Correlation between AI_MICRO and Operational Outcomes

Variables	SC_REL	TRANS_PERF	COLD_INT	SAFE_COMP
AI_MICRO	0.68**	0.63**	0.70**	0.65**

Note: p < 0.01

The results show strong positive correlations between AI-enabled microbiology and all operational outcomes. AI_MICRO correlated highest with Cold-Chain Integrity (r = 0.70), indicating that predictive monitoring and anomaly detection have a particularly strong impact on maintaining optimal environmental conditions during transport and storage of biological materials. Significant correlations with Supply Chain Reliability (r = 0.68), Transport Performance (r = 0.63), and Safety Compliance (r = 0.65) suggest that AI integration

strengthens overall operational efficiency and adherence to regulatory standards across teaching hospitals.

4.4 Regression Analysis

A multiple regression analysis was conducted to determine the predictive influence of AI_MICRO on SC_REL, TRANS_PERF, COLD_INT, and SAFE_COMP.

Table 3: Multiple Regression Analysis of AI_MICRO on Operational Outcomes

Dependent Variable	β	t	P
SC_REL	0.46	9.87	<0.001
TRANS_PERF	0.41	8.55	<0.001
COLD_INT	0.52	11.23	<0.001
SAFE_COMP	0.44	9.14	<0.001

The regression results indicate that AI_MICRO significantly predicts improvements in all operational outcomes. The strongest effect was observed on Cold-Chain Integrity ($\beta = 0.52$, $p < 0.001$), confirming that predictive analytics and real-time laboratory monitoring are critical for maintaining sample viability during transport. Supply Chain Reliability ($\beta = 0.46$), Transport Performance ($\beta = 0.41$), and Safety Compliance ($\beta = 0.44$) were also significantly influenced by AI adoption, demonstrating a robust operational impact across hospital logistics.

4.5 Regional Illustrations

Analysis across the six geopolitical zones revealed some contextual variations. Northern hospitals, such as University of Maiduguri Teaching Hospital and University of Abuja Teaching Hospital, Gwagwalada, reported slightly lower mean scores for Transport Performance ($M \approx 3.7$) due to infrastructural and climatic challenges, despite high AI_MICRO scores. Southern hospitals, including University of Benin Teaching Hospital and University College Hospital, Ibadan, exhibited higher Transport Performance ($M \approx 4.0$) and Cold-Chain Integrity ($M \approx 4.2$), reflecting more favourable infrastructure and human capacity for integrating AI insights into logistics. These findings reinforce the moderating role of contextual factors in operationalising AI in Nigerian teaching hospitals.

4.6 Summary of Key Findings

1. AI-enabled microbiology is widely adopted across Nigerian teaching

hospitals, particularly for predictive analytics, laboratory monitoring, and anomaly detection.

2. Positive and significant relationships exist between AI_MICRO and all operational outcomes: Supply Chain Reliability, Transport Performance, Cold-Chain Integrity, and Safety Compliance.
3. Predictive analytics most strongly impacts Cold-Chain Integrity, highlighting its critical role in maintaining sample viability.
4. Contextual factors such as infrastructure, human capacity, and geographic variability influence the magnitude of AI's impact, particularly in transport performance.

5. Discussion

The findings of this study provide robust evidence that AI-enabled microbiology significantly influences supply chain reliability, transport performance, cold-chain integrity, and safety compliance in Nigerian teaching hospitals. The positive correlations observed between AI_MICRO and operational outcomes ($r = 0.63-0.70$) indicate that predictive analytics and laboratory monitoring are not merely technological enhancements but critical enablers of operational efficiency. This aligns with international literature that emphasises the transformative potential of AI in healthcare logistics (Dubey et al., 2022; Li, Wang, & Xu, 2023) while providing context-specific evidence within Nigerian institutions.

Predictive analytics and cold-chain management emerged as particularly critical. The strongest regression coefficient was observed for Cold-Chain Integrity ($\beta = 0.52$), reflecting the importance of AI in maintaining optimal environmental conditions for biological samples and reagents during transport. Teaching hospitals such as University of Benin Teaching Hospital and University College Hospital, Ibadan demonstrated how AI alerts for temperature deviations and transport delays can prevent sample spoilage, reduce wastage, and maintain diagnostic reliability. This underscores AI's operational value in mitigating Nigeria-specific challenges such as inconsistent electricity supply, traffic congestion, and road infrastructure variability (Afolabi & Chukwu, 2024; Nguyen & Tran, 2023).

Supply Chain Reliability and Transport Performance were also significantly enhanced through AI adoption ($\beta = 0.46$ and 0.41 , respectively). Hospitals like University of Abuja Teaching Hospital, Gwagwalada, and University of Maiduguri Teaching Hospital benefited from predictive forecasting of reagent consumption and transport route optimisation, allowing preemptive adjustments in logistics schedules. These findings confirm that AI integration reduces the reliance on reactive operational decisions, shifting Nigerian hospital supply chains from a largely manual, reactive mode to a proactive, data-driven model.

However, the study also highlights contextual moderating factors that influence AI effectiveness. Infrastructure limitations, human capacity gaps, and environmental variability constrained the realisation of AI's full potential, particularly in northern hospitals. This finding resonates with previous Nigerian studies that emphasise infrastructural and human resource challenges as barriers to digital health adoption (Adebayo, Nwafor, & Oladipo, 2023; Johnson, Bello, & Akpan, 2026). Therefore, while AI offers transformative potential, its operational impact is contingent upon institutional readiness, policy support, and context-sensitive adaptation.

Overall, this study contributes to theory and practice by demonstrating that AI-enabled microbiology is not an isolated technological intervention but a strategic enabler of healthcare

logistics and transport efficiency. By linking laboratory intelligence to supply chain decisions, AI enhances predictive capacity, operational responsiveness, and compliance with safety standards, providing a model for other resource-constrained healthcare systems.

6. Recommendations

Based on the findings, several strategic recommendations are proposed to optimise AI integration in Nigerian teaching hospitals:

1. **Infrastructure Investment:** Hospitals should prioritise reliable electricity supply, internet connectivity, and robust IT infrastructure to ensure continuous AI operations. Backup systems and cloud-based solutions can mitigate local infrastructural challenges.
2. **Capacity Building:** Training programmes for laboratory scientists, supply chain officers, and transport personnel should be institutionalised to enhance technical literacy and proficiency in AI systems. Cross-training can ensure seamless integration between laboratory outputs and logistical decision-making.
3. **Policy and Regulatory Alignment:** The Federal Ministry of Health, in collaboration with the National Health ICT Framework, should develop clear guidelines on AI integration, data interoperability, and compliance with laboratory and transport safety standards.
4. **Contextualised AI Solutions:** AI systems should be customised to account for Nigeria-specific challenges, such as road networks, climatic variability, and resource constraints, ensuring predictive models are locally relevant and actionable.
5. **Sustainability Planning:** Hospitals should establish dedicated budgets for AI maintenance, system upgrades, and ongoing staff training, ensuring long-term adoption and operational resilience.

6. Cross-Hospital Collaboration:

Teaching hospitals across geopolitical zones can form networks to share best practices, AI models, and predictive analytics insights, fostering system-wide efficiency improvements and knowledge transfer.

7. Conclusion

This study confirms that AI-enabled microbiology significantly enhances supply chain and transport management in Nigerian teaching hospitals, providing empirical evidence that predictive analytics and real-time laboratory monitoring improve operational efficiency, cold-chain integrity, and regulatory compliance. The strongest impact was observed in Cold-Chain Integrity, highlighting the critical role of AI in maintaining sample viability during transport and storage.

However, contextual challenges, including infrastructural limitations, human capacity gaps, and policy inconsistencies, moderate AI effectiveness, demonstrating that technology adoption must be coupled with strategic investments and institutional readiness. Nigerian teaching hospitals, including University of Abuja Teaching Hospital, Gwagwalada, University College Hospital, Ibadan, University of Benin Teaching Hospital, and others across the six geopolitical zones, exemplify how AI adoption, when integrated with logistics and supply chain planning, can improve healthcare delivery outcomes.

In conclusion, AI in microbiology is not a peripheral innovation but a strategic enabler of operational resilience and supply chain optimisation. Its effective implementation requires context-sensitive adaptation, capacity development, and infrastructural investment, offering a model for other resource-constrained healthcare systems both within Nigeria and globally.

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