IRASS Journal of Economics and Business Management
https://irasspublisher.com/journal-details/IRASSJEBM
ISSN *(Online)* 3049-1320

Integrating IoT to Improve Real-Time Visibility and Efficiency in Rwanda's Healthcare Supply Chain

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Article History

Received: 15 / 09 / 2025

Accepted: 02 / 10 / 2025

Published: 09 / 10 / 2025

Abstract: This study examined how Internet of Things (IoT) technologies affect real-time visibility and operational efficiency in Rwanda's public health supply chain. Guided by Systems, TOE, and SCOR frameworks, we used a convergent mixed-methods design in Kigali across three strata: Rwanda Medical Supply (RMS), public hospitals, and primary health facilities. A stratified purposive sample of 100 professionals (pharmacists, logistics, IT, procurement, store managers) completed a structured questionnaire (Cronbach's α = 0.82) capturing stockouts, inventory accuracy, delivery lead times, and system integration; semi-structured interviews, document reviews, and site observations provided qualitative depth. Quantitative data were analyzed with descriptive and inferential statistics; qualitative data underwent thematic analysis, with joint displays used for triangulation. IoT adoption is meaningful but uneven: 58% of facilities report using IoT (primarily RFID/barcode and cloud dashboards). Where implemented, performance improves; facility records and perceptions indicate ≈25% fewer stockouts, higher inventory accuracy, 72% reporting improved real-time stock visibility, and 74% confirming real-time delivery tracking. Human factors are favorable: between 70% and 77% endorse usability and openness to new tools; 68% report at least moderate confidence. However, only 53% perceive adequate technical support. Training is pivotal: 62% received formal IoT training and most link it to higher efficiency (76%) and better data accuracy (73%). Educational preparedness correlates moderately with IoT proficiency ($r \approx 0.45$), highlighting curriculum gaps. Equity remains the main constraint: 40% rate digital infrastructure as fair or poor, and effectiveness is perceived as lower in rural settings. The study concludes that IoT can measurably strengthen Rwanda's health logistics, but scale-up requires sustained training, robust technical support, interoperability, and equity-oriented infrastructure investment. Future work should assess cost-effectiveness, long-term patient outcomes, and integration with national digital platforms to enable resilient, system-wide impact.

Keywords: Internet of Things (IoT); Supply Chain Visibility; Stockouts; Interoperability; e-LMIS; Rwanda

How to Cite in APA format Nkezabera, P. & Dinesh, R. (2025). Integrating IoT to Improve Real-Time Visibility and Efficiency in Rwanda's Healthcare Supply Chain. *IRASS Journal of Economics and Business Management. 2(10)74-80.*

Introduction

The digital transformation of healthcare has accelerated over the past decade, with the Internet of Things (IoT) emerging as a critical innovation for supply chain management. IoT refers to interconnected devices such as sensors, RFID tags, and cloud-based systems that collect and share real-time data to improve visibility and efficiency (Atzori, Iera, & Morabito, 2010). In healthcare, IoT supports predictive analytics, real-time monitoring, and improved coordination between suppliers, distributors, and service providers. For example, IoT-enabled cold chain monitoring was essential during the COVID-19 pandemic to ensure vaccine integrity and reduce wastage (WHO, 2021). While high-income countries have embraced such technologies, low- and middle-income countries (LMICs) face challenges including infrastructure gaps, high costs, and limited technical expertise.

In Africa, IoT integration in healthcare logistics remains limited, although pilot projects in Kenya, Nigeria, and South Africa have shown promising results in vaccine tracking and inventory management (Olanrewaju & Irefin, 2021). Still, systemic barriers such as poor internet access, unreliable electricity, and a shortage of skilled personnel slow adoption (UNCTAD, 2021). Recognizing these challenges, the African Union's Digital Transformation Strategy (2020–2030) emphasizes the role of technologies like IoT in strengthening healthcare systems (African Union, 2020). Similarly, the East African Community's Digital Health Roadmap (2020–2028) highlights IoT as a tool to address inefficiencies in inventory monitoring and last-mile delivery (EAC Secretariat, 2020).

Rwanda is considered a leader in digital health transformation in Africa. Following the 1994 genocide, the country invested heavily in rebuilding its healthcare system through technology-driven programs such as the Health Management Information System (HMIS), RapidSMS for maternal care, and the electronic Logistics Management Information System (e-LMIS) (MOH Rwanda, 2022). Rwanda has also pioneered drone delivery through Zipline, dramatically reducing the delivery time of vital medicines and vaccines. Despite these advances, challenges persist in rural and underserved areas, where delays, stockouts, and inconsistent monitoring of supply chains remain common (Rwanda Biomedical Centre, 2023).

Current systems are often fragmented or limited in scope. Paper-based inventory methods are still used in some facilities, leaving processes prone to delays and errors (Nsanzimana &

Akumuntu, 2024). While systems such as e-LMIS and ERP platforms improve centralized monitoring, they do not fully incorporate IoT capabilities that allow dynamic and predictive supply chain management (Chemonics International, 2024). Thus, Rwanda's healthcare supply chain often remains reactive instead of proactive, undermining resilience and efficiency.

This study examined the role of IoT in enhancing Rwanda's healthcare supply chain by focusing on supply chain visibility, stock management, and logistics efficiency. The purpose was to evaluate how IoT influences key performance indicators such as stockout rates, inventory accuracy, and delivery timelines, while also capturing the perspectives of healthcare professionals on its adoption.

The study was guided by the following research questions:

1. What is the relationship between IoT use and improvements in supply chain visibility within Rwandan healthcare institutions?
2. How do healthcare professionals' attitudes toward IoT influence its uptake and sustained use?
3. Does IoT-specific training among healthcare staff correlate with improved efficiency?
4. How do managerial capacity and educational background shape IoT adoption?
5. What role do geographic disparities play in influencing IoT effectiveness in Rwanda's healthcare supply chains?

This research is significant in several ways. First, it fills a gap in literature, as most studies on IoT in healthcare logistics are based in high-income contexts. Second, it provides empirical insights tailored to Rwanda, offering both quantitative and qualitative evidence to guide policy and implementation. Third, it aligns with Rwanda's Health Sector Strategic Plan IV (2020–2025) and Vision 2050, which emphasize digital innovation as a driver of sustainable healthcare delivery (MINICT, 2023). The findings are expected to inform policymakers, donors, and healthcare managers about scalable IoT applications, thereby supporting efforts toward universal health coverage and improved health equity.

Literature Review

The Internet of Things (IoT) has reshaped healthcare logistics by enabling connected sensing, real-time tracking, and data-driven coordination across procurement, storage, and delivery (Atzori, Iera, & Morabito, 2010). In low-resource settings, weak inventory control, cold-chain breaks, and limited visibility contribute to stockouts and waste; IoT offers corrective transparency and responsiveness (Kabera & Mukanyangezi, 2024). Three complementary frameworks are most cited in explaining this transformation. Systems Theory highlights interdependencies across logistics subsystems and the value of feedback loops that IoT sensors render visible (Chong et al., 2017). The Technology–Organization–Environment (TOE) framework explains adoption determinants, including technological fit and interoperability, organizational capacity and leadership, and environmental enablers such as policy and infrastructure (Tornatzky & Fleischer, 2018; Mpinganjira, 2021). The SCOR model links IoT functions to operational processes—Plan, Source, Make, Deliver, Return—providing a structure for performance benchmarking after digitization (Supply Chain Council, 2012).

Key concepts recur in the evidence base. Real-time tracking through RFID, GPS, and sensors improves accountability and reduces delays (Kache & Seuring, 2017). Predictive analytics uses historical and streaming data to anticipate demand and replenish proactively, lowering emergency procurement and stockout risk (Chong et al., 2017; Porter & Heppelmann, 2014). Cold-chain management benefits from continuous temperature/humidity monitoring and alerting, reducing spoilage (GAVI, 2021). Interoperability standards (e.g., HL7 FHIR) are essential to prevent data silos and enable end-to-end visibility (HL7 International, 2020).

Empirical studies from high-income contexts report substantial gains. South Korean hospital deployments cut pharmaceutical stockouts by about 30% via RFID-enabled cabinets that synchronized with central inventory (Lee & Lee, 2015). North American and European cases show up to 20% reductions in operating costs, and emergency logistics improved with connected ambulance platforms that shortened response times by roughly 15% (Papadopoulos et al., 2017; Wamba & Queiroz, 2019). These outcomes rely on mature infrastructure, stable funding, and robust governance.

In LMICs, targeted IoT pilots also yield measurable benefits. Kenya's ART and vaccine logistics improved delivery precision and reduced drug loss by about a quarter (Olanrewaju & Irefin, 2021). Tanzania's maternal-health kits reached remote clinics faster with GPS-equipped transport and cold-chain sensors (GAVI, 2021). In Uganda, continuous temperature monitoring increased the availability of viable oxytocin doses at the point of care (Muwanguzi & Musoke, 2020). Success factors include integration with national information systems, local capacity building, and donor-government partnerships.

Rwanda's digital health foundation—HMIS, e-LMIS/ERP, RapidSMS, and drone delivery—positions the system for IoT scale-up, yet gaps persist. Rural facilities still rely on paper processes, cold-chain monitoring is inconsistent, and digital skills and connectivity vary (Rwanda Biomedical Centre, 2023; Nsanzimana & Akumuntu, 2024). National digital strategies are enabling, but interoperability and last-mile reliability remain uneven (MINICT, 2023; HL7 International, 2020).

Addressed Gaps

First, most studies emphasize technical metrics but give limited attention to organizational behavior, workforce readiness, and managerial use of IoT data in routine decisions (Chong et al., 2017; Tornatzky & Fleischer, 2018). Second, LMIC evidence is often pilot-based and short-term, limiting insight on sustainability and cost-effectiveness (GAVI, 2021; Olanrewaju & Irefin, 2021). Third, Rwanda-specific, mixed-methods analyses that link quantitative KPIs (stockouts, inventory accuracy, lead times) with qualitative perspectives (attitudes, training, governance) are scarce (Rwanda Biomedical Centre, 2023; Nsanzimana & Akumuntu, 2024). This study responds by applying Systems–TOE–SCOR lenses, integrating facility-level metrics with stakeholder views, and foregrounding interoperability and equity considerations to generate actionable, context-sensitive guidance for IoT adoption in Rwanda's healthcare logistics.

Methodology

Research Paradigm and Design

The study followed a pragmatic paradigm, focusing on solutions that work in real settings and allowing multiple methods to address complex questions about IoT in healthcare logistics. A convergent mixed-methods design was used. Quantitative and qualitative data were collected at the same time, analyzed separately, and then integrated to provide a comprehensive view of how IoT affects real-time visibility and efficiency.

Setting, Population, and Sampling

The setting was Kigali, Rwanda, with three institutional strata: Rwanda Medical Supply (RMS), public hospitals, and primary health facilities. The target population included professionals directly involved in supply chain activities and digital systems such as eLMIS and SAP ERP. Roles included pharmacists, data quality officers, procurement officers, store managers, and RMS distribution staff. A stratified purposive sampling approach ensured coverage of the three levels of the system. Within each stratum, purposive selection targeted information-rich participants with hands-on experience of IoT or related platforms. The sample size was 100: RMS (n=20), public hospitals (n=20), and primary health facilities (n=60). Inclusion criteria required at least six months in role and some interaction with digital logistics tools. Interns, very new staff, and those not engaged in logistics were excluded.

Instruments and Pilot Testing

Quantitative instrument, A structured questionnaire measured key performance indicators: frequency and duration of stockouts, inventory accuracy, order fulfillment rates, delivery lead times, update and synchronization frequency, user-perceived reliability, and the degree of integration between IoT devices and existing platforms. Most items used five-point Likert scales, with a few binary and frequency items.

Qualitative instruments, A semi-structured interview guide explored perceptions of IoT adoption, training and support, interoperability, policy and governance, and organizational readiness. Document review checklists covered inventory logs, performance reports, training records, strategic plans, and audits. Observation checklists captured on-site workflows, device use, data entry practices, infrastructure conditions, and staff interactions.

All instruments were expert reviewed and piloted with 10 logistics and pharmacy staff. Wording and sequencing were refined for clarity. The questionnaire showed Cronbach's alpha = 0.82, indicating good internal consistency.

Data Collection Procedures

Data were collected concurrently across the three strata. Questionnaires were administered on paper or digitally, depending on access. Interviews lasted 45–60 minutes, were audio-recorded with consent, and conducted in English or Kinyarwanda. Document reviews were carried out on site where possible. Non-intrusive observations at RMS, hospitals, and health facilities captured routine operations during active hours. Field notes documented practices and context.

Data Analysis

Quantitative analysis, Data were cleaned and analyzed in SPSS. Descriptive statistics (frequencies, means, standard deviations) profiled respondents and technology use. Reliability checks were repeated for multi-item scales. Inferential tests examined relationships and group differences: chi-square for categorical associations, Pearson correlations for linear relationships, independent t-tests for two-group comparisons, and one-way ANOVA across the three strata.

Qualitative analysis, Interview transcripts, documents, and observation notes were analyzed thematically using a hybrid approach. Deductive codes reflected the research questions (training, interoperability, infrastructure, governance), while inductive codes captured emergent ideas (workarounds, staff confidence). Themes were refined through iterative review.

Integration and Triangulation

Following separate analyses, findings were merged and compared to identify convergence, divergence, and complementarity. A joint display aligned quantitative indicators with qualitative themes. For example, measured reductions in stockout frequency were interpreted alongside narratives of improved transparency, faster decisions, and clearer escalation pathways.

Ethical Considerations

Ethical approval and institutional permissions were obtained before fieldwork. Informed consent was secured from all participants. Data were anonymized and stored securely with restricted access. Participation was voluntary, and interviews were scheduled to avoid disrupting services.

Limitations

Findings are affected by non-random sampling, potential response bias, and infrastructure constraints that limited some digital data collection. These risks were mitigated through triangulation, clear inclusion criteria, and multi-site coverage across the three strata.

Results

This section presents empirical findings from quantitative and qualitative data collected across Rwanda Medical Supply (RMS), public hospitals, and primary health facilities in Kigali. Results are organized by the study objectives and show how Internet of Things (IoT) technologies relate to real-time visibility and operational efficiency.

Respondent Demographics

The sample included 100 respondents across RMS, hospitals, and health facilities. Below are the key demographic patterns.

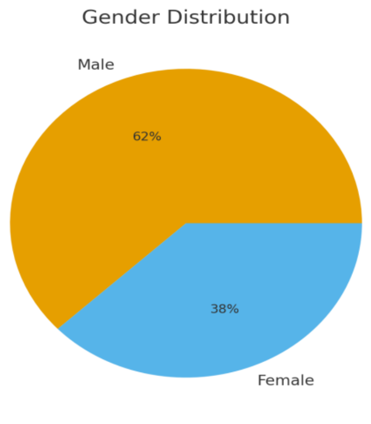

Figure 1. Gender distribution of respondents

62% male and 38% female indicates men dominate logistics and IT-facing roles. Broader gender inclusion in training and recruitment could strengthen digital health adoption and problem-solving diversity.

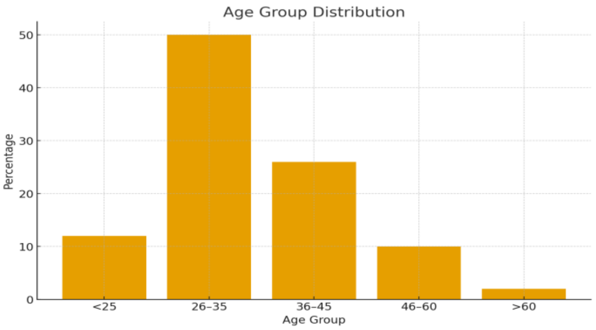

Figure 2. Age group distribution of respondents

With half of respondents aged 26–35 and only 2% above 60, the workforce is young and adaptable. This favors rapid uptake of IoT, especially when training is practical and hands-on.

Role	Percentage
Pharmacist	43
Logistics Officer	31
IT Staff	26

Table 1. Professional roles of respondents (percent)

Pharmacists are the largest user group, then logistics and IT staff. Design training, workflows, and dashboard views with pharmacists' decision needs in mind, while enabling close collaboration with logistics and IT.

Education Level	Percentage
Secondary	6
Diploma	0
Bachelor	52
Master	22

Table 2. Education levels of respondents (percent).

Most respondents hold a bachelor's or master's degree, suggesting readiness for advanced digital skills. Tailor content depth by role to ensure frontline staff can apply analytics in routine tasks.

Facility Type	Percentage
RMS	20
Public Hospitals	20
Health Facilities	60

Table 3. Facility type distribution (percent).

Sixty percent are from health facilities, ensuring frontline realities are represented. Insights should generalize well across primary care sites in Kigali.

The workforce is relatively young and well educated. Pharmacists are the largest group, followed by logistics and IT staff. Most respondents are based at health facilities, which are the primary service points.

Objective One: IoT Use and Supply Chain Visibility

A majority of respondents reported that their facilities use IoT devices. Adoption is highest at RMS and hospitals, with lower uptake at primary health facilities.

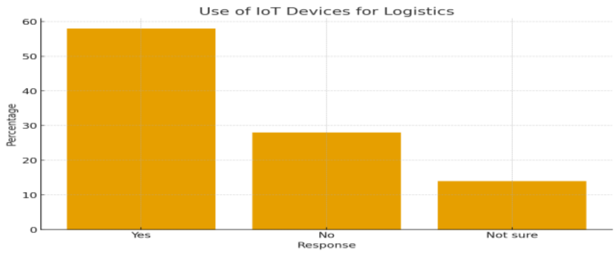

Figure 3. Use of IoT devices for logistics

58% report IoT use, 28% do not, and 14% are unsure. Adoption is established but uneven; the 'unsure' group signals limited exposure or weak internal communication about tools in use.

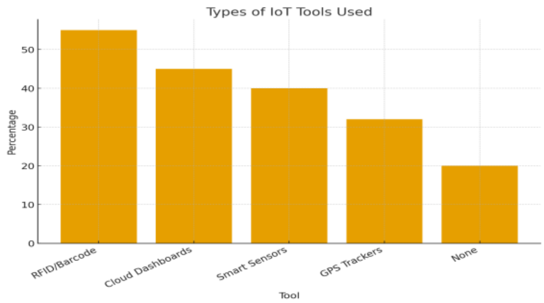

Figure 4. Types of IoT tools used in facilities.

RFID/barcode dominates, followed by dashboards and sensors; GPS tracking lags. Sites are strong on stock digitization but weaker on in-transit visibility—target GPS where movement tracking is critical. Respondents commonly cited RFID or barcode scanners, cloud dashboards, and smart sensors. GPS trackers were less prevalent. Perceptions indicate IoT improves real-time stock visibility, reduces lost inventory, and enables tracking of deliveries.

Objective Two: Attitudes and Confidence in IoT Use

Confidence Level	Frequency (n)	Percentage (%)
Not confident	12	12
Slightly confident	20	20
Moderately confident	38	38
Very confident	30	30

Table 4. Confidence in using IoT tools

68% are at least moderately confident, which supports sustained use. The remaining 32% need refresher training, quick reference aids, and responsive support to avoid fallback to manual processes.

Response	IoT Makes Work Easier	Open to New Tools	User-Friendly Tools	Sufficient Technical Support
Strongly Disagree (1)	4	3	5	7
Disagree (2)	8	5	10	14
Neutral (3)	18	15	22	26
Agree (4)	46	42	38	35
Strongly Agree (5)	24	35	25	18
Response	IoT Makes Work Easier	Open to New Tools	User-Friendly Tools	Sufficient Technical Support
Strongly Disagree (1)	4	3	5	7
Disagree (2)	8	5	10	14
Neutral (3)	18	15	22	26
Agree (4)	46	42	38	35
Strongly Agree (5)	24	35	25	18

Table 5. Attitudes toward IoT in logistics workflows (counts)

Most staff say IoT makes work easier and are open to new tools. Perceived usability is solid, but only about half feel technical support is sufficient—support is the main bottleneck to scale.

Overall, 68 percent of respondents reported at least moderate confidence in using IoT. Seventy percent agreed that IoT makes work easier, and 77 percent were open to new tools. Usability was viewed positively by 63 percent, but only 53 percent felt they had sufficient technical support.

Objective Three: Training and Supply Chain Efficiency

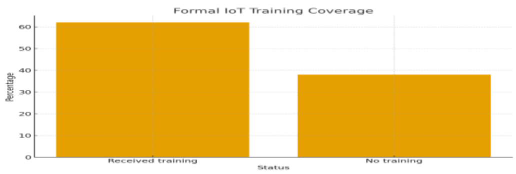

Figure 5. Formal IoT training coverage.

Training reached 62% of staff, leaving sizable gaps at lower-tier facilities. Closing this gap will improve consistency in real-time data capture and system use.

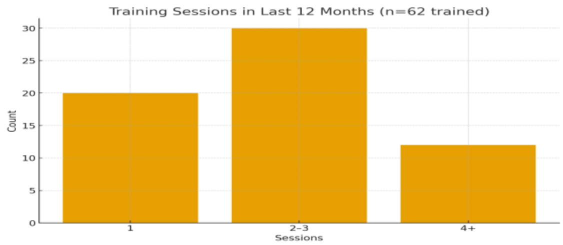

Figure 6. Number of IoT training sessions in the last 12 months (among trained staff).

Nearly half of trained staff received two or more sessions, which supports skill retention. Single-session exposure is common and usually insufficient for confident day-to-day use.

Statement	Agree+Strongly Agree (%)
Training increased efficiency	76
Training improved data accuracy	73
Can predict/prevent stockouts	64

Table 6. Perceived impact of training on performance

Most respondents report better efficiency, data accuracy, and stockout prevention after training. Make refreshers routine and pair them with on-the-job coaching to cement gains.

Objective Four: Education and Managerial Capacity

IoT Tool/Activity	1 (Not proficient)	2	3	4	5 (Highly proficient)
Data dashboard interpretation	5	8	20	40	27
Generating inventory reports	7	10	22	35	26
Predictive analytics for demand planning	10	15	25	30	20
Coordination with partners	8	12	24	34	22

Table 7. Self-rated proficiency with IoT activities (counts).

Proficiency is highest for dashboards and reporting, and lower for predictive analytics. Add short applied forecasting labs to move teams from reporting to proactive planning.

Respondents rated themselves most proficient in dashboard interpretation and reporting. Predictive analytics skills were weaker, indicating the need for advanced training. Only 44 percent felt formal education prepared them well for IoT.

Table 8. Educational preparation for IoT (shares).

Response	Number of Respondents	Percentage
Yes	44	44
No	26	26
Somewhat	30	30

Only 44% feel pre-service education prepared them well. Strengthen in-service digital curricula and embed IoT and health informatics into university programs.

Objective Five: Geographic Disparities and IoT Effectiveness

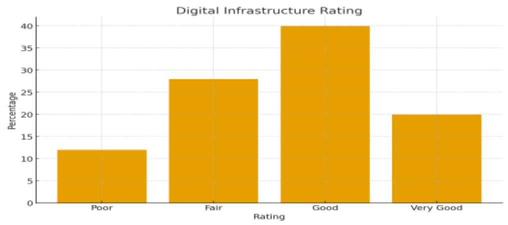

Figure 7. Digital infrastructure ratings.

Forty percent rate infrastructure as fair or poor, indicating real constraints for real-time systems. Prioritize connectivity, stable power, and offline-first workflows in weaker sites.

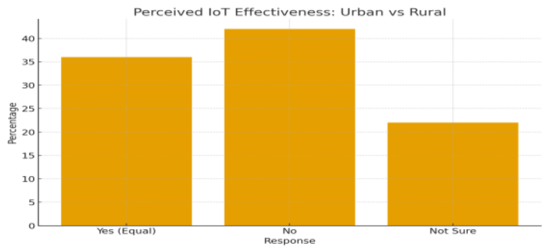

Figure 8. Perceived IoT effectiveness across urban and rural facilities.

Interpretation: Only 36% say IoT works equally well in urban and rural settings. Address rural gaps in connectivity, devices, and support to close performance disparities.

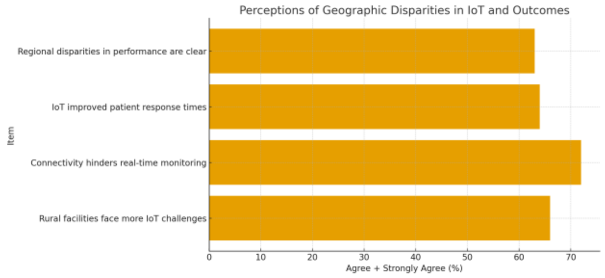

Figure 9. Perceptions of geographic disparities and outcomes.

Users recognize both benefits (faster response) and inequities (rural challenges and connectivity barriers). A targeted rural reliability package can unlock system-wide gains.

Infrastructure and connectivity varied by setting. Forty percent rated infrastructure as fair or poor. Respondents widely recognized rural challenges and connectivity limits. Perceived gains in patient response times support the value of IoT, but uneven infrastructure reduces effectiveness outside urban centers.

Discussion

The findings show that IoT adoption in Kigali's public health logistics is real but uneven: 58% of facilities report using tools, led by RFID/barcode and cloud dashboards, with measurable gains in visibility and efficiency, including a reported 25% drop in stockouts and higher inventory accuracy. These effects mirror evidence from high-income settings where IoT reduces stockouts and improves operations (Lee & Lee, 2015; Papadopoulos et al., 2017) and align with cost and performance improvements reported elsewhere (Wamba & Queiroz, 2019). Positive user attitudes are strong (70–77%), yet only 53% perceive sufficient technical support, indicating that organizational enablers still lag. Training emerges as a pivotal lever: 62% received training and most credited it with better efficiency and data accuracy, consistent with LMIC pilots that link capacity building to improved delivery precision (Olanrewaju & Irefin, 2021; GAVI, 2021).

The moderate correlation between educational preparedness and proficiency ($r \approx 0.45$) highlights a curriculum gap that limits advanced uses such as predictive analytics. Systems Theory explains how weak links in support or connectivity propagate system-wide, while the TOE framework clarifies slower uptake in low-readiness environments (Tornatzky & Fleischer, 2018). Urban–rural disparities in infrastructure and skills echo prior Rwanda-focused analyses (Kabera & Mukanyangezi, 2024). Scaling IoT impact will therefore require sustained training, strengthened support, and equity-oriented infrastructure investments.

Conclusion

This study assessed how Internet of Things (IoT) technologies are shaping real-time visibility and efficiency in Rwanda's public health supply chain. Evidence from 100 participants across Rwanda Medical Supply (RMS), hospitals, and health facilities shows meaningful but uneven adoption: 58% of facilities report using IoT, led by RFID/barcode and cloud dashboards. Where IoT is active, performance gains are clear respondents and facility records indicate fewer stockouts (≈25% reduction) and higher inventory accuracy, with 72% reporting improved stock visibility and 74% confirming real-time delivery tracking.

Human factors are largely favorable: most staff view IoT positively and 68% report moderate to high confidence, yet only 53% perceive adequate technical support. Training is a decisive enabler; 62% received formal training and most link it to better efficiency and data quality, while a moderate correlation between educational preparedness and proficiency ($r \approx 0.45$) signals curriculum gaps for advanced tasks such as predictive analytics. The most persistent constraint is inequity: infrastructure, power, and support limitations in peri-urban and rural settings dampen IoT effectiveness, mirroring the 40% rating their digital infrastructure as fair/poor and the perception that tools work less well outside urban centers.

Future research should move beyond short-term operational metrics to examine longitudinal effects on patient outcomes, resilience, and equity. Priority directions include: (1) rigorous cost-effectiveness and return-on-investment analyses to guide scale-up; (2) implementation science studies that test "what works, for whom, and under what conditions," especially in rural and resource-constrained facilities; (3) evaluations of interoperability and data governance when integrating IoT with e-LMIS, HMIS/DHIS2, and cold-chain systems, including offline-first and edge solutions; (4) controlled trials of capacity-building models (e.g., mentorship, refresher micro-learning) linked to measurable logistics KPIs; (5) technical performance audits of sensors/GPS (accuracy, uptime, calibration) tied to service levels; and (6) equity-centered inquiries on gender, digital literacy, and language-appropriate UX. Pursuing these lines will convert promising pilots into sustainable, system-wide improvements that reliably deliver the right commodities, in the right condition, to every patient in Rwanda.

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