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INTERNET OF THINGS FOR FACILITY SUPPLY CHAIN MANAGEMENT IN TRANSPORT OPERATIONS

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Abstract

The Internet of Things (IoT) is transforming supply chain management, particularly in transportation operations. This study investigates how IoT technologies can enhance efficiency, visibility, and performance in facility supply chain management within the transport sector. Through a mixed-method approach, combining qualitative interviews, a quantitative survey, and case studies, the research examines IoT's potential to enable real-time monitoring, predictive maintenance, and optimized logistics. Findings indicate that IoT adoption can reduce operational costs by 15-20% and improve delivery times, though challenges such as cybersecurity risks, high costs, and integration complexities persist. This paper contributes to the discourse on IoT's role in supply chain innovation by offering recommendations for future research and practical application.

Keywords: Operational efficiency, IoT adoption, Descriptive statistics, Transport logistics, Methodology, Regression analysis

1. Introduction

The rapid advancements in digital technology are reshaping industries globally, with the Internet of Things (IoT) at the forefront of this transformation. Within the context of supply chain management (SCM), IoT technologies offer significant opportunities to enhance operational efficiency, transparency, and decision-making. The transportation sector, a critical link in the supply chain, stands to benefit substantially from IoT applications by enabling real-time data exchange between vehicles, facilities, and logistics systems. This connectivity facilitates the seamless flow of goods and information across the supply chain, contributing to improved resource utilization, reduced operational costs, and enhanced service quality (Udeh and al., 2024; Sallam and al., 2023). IoT involves connecting physical devices to the internet, allowing them to autonomously collect and exchange data through sensors, RFID tags, GPS trackers, and smart systems (Ur Rehman and al., 2024). These technologies provide real-time insights into various aspects of transportation, including vehicle location, temperature conditions, and equipment performance. While IoT has already demonstrated significant potential in sectors such as manufacturing and services (Iqbal, 2024; Raj and al., 2023; Akyuz

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and Balkan, 2023), its application in transportation logistics remains an area with both opportunities and challenges. Despite its potential, the implementation of IoT in transportation logistics is hindered by several critical challenges. Foremost among these are cybersecurity concerns, requiring robust measures like two-factor authentication and end-to-end encryption (Mishra and Yadav, 2022). Additionally, issues related to scalability, data integration, privacy, high implementation costs, and the complexity of integrating IoT with existing systems pose significant obstacles (Nithya and Shanthi, 2024). Overcoming these challenges is crucial to fully realizing the benefits of IoT in optimizing traffic flow, enhancing safety, and minimizing environmental impacts within supply chain operations (Mishra and Yadav, 2022).

This study aims to explore how IoT can improve operational efficiency, visibility, and overall performance in transport operations within facility supply chain management. Specifically, it addresses the key research question: "To what extent does IoT adoption enhance efficiency, visibility, and cost-effectiveness in transportation logistics?". To answer this question, the study pursues the following objectives:

- Assess the impact of IoT infrastructure investment on operational cost reduction.
- Evaluate how IoT integration improves process transparency and efficiency.
- Analyze the relationship between system integration levels and stakeholder satisfaction in transportation logistics.

For that, we propose two hypotheses: (1) Investment in IoT infrastructure significantly reduces operational costs, and (2) IoT integration improves process transparency and efficiency. These hypotheses are based on three key variables include IoT investment, system integration and cost reduction. Our paper is structured as follows: The next section reviews the existing literature on IoT applications in supply chain management and transportation. The methodology used for the study is then outlined, followed by the presentation of results and discussion. Finally, the conclusion summarizes the key insights and suggests directions for future research.

2. Literature review

The integration of the IoT into supply chain management (SCM) has emerged as a pivotal focus in recent scholarship, driven by its capacity to enhance operational transparency and efficiency (Rahimi and al., 2024). IoT technologies—encompassing sensors, RFID systems, and GPS trackers—enable the real-time tracking of goods and assets, fundamentally reshaping logistics and transportation operations. Studies such as those by Zrelli and Rejeb (2024) and Taj and al. (2023) emphasize how these tools provide actionable data on shipment locations and conditions, facilitating optimized decision-making and reducing operational expenses. Within the transportation sector, IoT has proven particularly valuable. For instance, McFarlane and al. (2003) demonstrated that real-time vehicle performance monitoring can lower fuel consumption and maintenance costs, while Zrelli and Rejeb (2024) and Taj and al. (2023) highlighted the role of dynamic routing in improving last-mile delivery efficiency. These advancements extend beyond transit to warehouse management, where IoT minimizes stock discrepancies and enhances inventory control (Mishra and Yadav, 2022). Theoretically, IoT's impact can be understood through frameworks like systems theory, which views supply chains as interconnected networks of physical and digital components (Alavi and al., 2018). This perspective underscores how IoT bridges operational silos, creating a cohesive ecosystem that

supports adaptive logistics. Beyond efficiency, IoT contributes to sustainability by optimizing resource use and reducing waste, as noted by Sallam and al. (2023). For example, predictive maintenance enabled by IoT sensors can extend equipment lifespan and decrease downtime, offering both economic and environmental benefits (Elkateb and al., 2024). Additionally, IoT strengthens supply chain transparency, fostering regulatory compliance and supplier accountability. Despite these advantages, the literature consistently identifies significant challenges to IoT adoption. Cybersecurity stands out as a primary concern, with the proliferation of connected devices amplifying risks of data breaches and cyberattacks (Niyato and al., 2016; De La Torre Parra and al., 2020). The technical complexity of integrating IoT with legacy systems further complicates implementation, often requiring substantial infrastructure investments and specialized expertise (Ur Rehman and al., 2024). These barriers are particularly pronounced for small and medium-sized enterprises (SMEs), which may lack the resources of larger firms. Moreover, the absence of standardized IoT protocols hinders interoperability, slowing broader uptake (Nithya and Shanthi, 2024). While the potential of IoT to transform transportation operations is widely acknowledged, gaps in the research remain evident. Much of the existing work focuses on short-term outcomes, with fewer studies exploring IoT's long-term effects on supply chain resilience—especially in the face of disruptions like the COVID-19 pandemic (Ansari and al., 2025)). Similarly, the synergy between IoT and emerging technologies, such as artificial intelligence, remains underexplored, despite its promise for creating autonomous supply chains (Yesodha and al., 2023).

3. Methodology

This study employs a mixed-method design to evaluate IoT's impact on transportation operations, blending qualitative and quantitative approaches across three phases: data collection, analysis, and validation.

- *Data collection*: Primary data were gathered via semi-structured interviews with 10 logistics experts, selected purposively for their over 10 years of experience in the field. Conducted via video calls, each 45-minute interview was recorded with consent and guided by open-ended questions on IoT benefits and barriers. Additionally, a survey was distributed to 80 logistics firms actively using IoT, selected from a total population of 200 companies[2] that actively use IoT in managing their supply chain. The sample size was determined using *Slovin's formula* which is written as: $n = N/(1+N*e^2)$. Where: n: sample size required; N: population size; e: is a specified margin of error (10%). This yields a required sample size of approximately 67 firms, our sample of 80 exceeds this threshold, ensuring sufficient statistical power at a 95% confidence level to detect meaningful effects, as evidenced by significant findings (e.g., $p < 0.001$ in regression analysis). The survey was developed from prior studies (Sallam and al., 2023), pre-tested with five managers, and administered online. Secondary data were sourced from academic literature and industry reports.

- *Data analysis*: Quantitative survey responses were analyzed using SPSS, with descriptive statistics (e.g., means, standard deviations) summarizing key performance indicators (KPIs) and regression analysis exploring IoT's influence on outcomes like cost reduction. The survey's internal consistency was confirmed with a Cronbach's Alpha of

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0.82. Qualitative interview data were processed using *NVivo* for thematic analysis, identifying recurring patterns such as cybersecurity concerns.

- *Validation*: Three case studies of logistics firms—varying in size and scope—were reviewed to contextualize findings, offering practical insights into IoT's real-world application.

4. Results

This section presents the empirical findings from the mixed-method analysis of IoT's impact on facility supply chain management in transportation operations, derived from survey data, expert interviews, and case studies.

4.1 Quantitative results

Survey responses from 80 logistics firms indicated that IoT adoption significantly enhances operational performance. To quantify these effects, descriptive statistics were calculated for key performance indicators (KPIs). The mean μ_X for each KPI was computed as:

$$\mu_X = \frac{1}{n} \sum_{i=1}^{n} X_i \quad (\mathbf{1})$$

Where X_i represents individual data points and n is the sample size (n = 80). The standard deviation σ_X measuring data variability, was calculated as:

$$\sigma_W = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \mu_X)^2} \quad (\mathbf{2})$$

For instance, firms reported an average cost reduction of 18% (μ_X=18%) with a standard deviation of 3.5% (σ_W =3.5%), indicating consistent savings across respondents attributable to real-time vehicle monitoring and predictive maintenance. Similarly, delivery times decreased by 10-15%, reflecting enhanced route optimization enabled by IoT systems.

To explore the relationship between IoT implementation and these outcomes, a multiple linear regression analysis was conducted. The model used cost reduction as the dependent variable (Y) and included independent variables such as IoT infrastructure investment (X_1) and system integration level (X_2), expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \varepsilon \quad (\mathbf{3})$$

Where:

- Y is the dependent variable (e.g., cost reduction).
- β_0 is the intercept.
- $\beta_1, \beta_2, \ldots, \beta_k$ are the regression coefficients.
- $X_1, X_2, \ldots, X_k$ are the independent variables (IoT factors).
- ε is the error term.

The results yielded significant coefficients: $\beta_1 = 0.45$ ($t = 5.23$, $p < 0.001$) for infrastructure investment and $\beta_2 = 0.38$ ($t = 4.12$, $p = 0.002$) for integration, with an R^2 of *0.68*, meaning 68% of the variance in cost reduction is explained by these IoT factors.

Hypothesis testing further validated these findings. The null hypothesis (H_0: no relationship between IoT adoption and KPIs) was tested using *t-statistics*, and with *p-values* below 0.05 (e.g., p = 0.001 for X*1*), H_0 was rejected, confirming IoT's significant impact. The survey's reliability was assessed with a Cronbach's Alpha of 0.82, indicating strong internal consistency of the measurement scale.

4.2 Qualitative results

Thematic analysis of semi-structured interviews with 10 logistics experts, each with over a decade of experience in transportation operations, uncovered three prominent themes related to IoT adoption, shedding light on both its challenges and perceived value. These insights were further validated and expanded through an examination of three case studies involving logistics firms of varying sizes and operational scopes, providing a practical lens on the qualitative findings.

- Cybersecurity risks

The first recurring theme was the significant apprehension surrounding cybersecurity, with all 10 experts identifying it as a critical barrier to IoT implementation. They emphasized the vulnerability of IoT devices to data breaches and unauthorized access, given their constant connectivity. One expert remarked, "Data breaches are a constant worry with connected systems—every sensor is a potential entry point for hackers." Another highlighted a specific incident where a fleet management system was compromised, delaying operations and exposing sensitive shipment data. This concern was not merely theoretical; experts noted that the increasing volume of data generated by IoT devices—such as vehicle locations and cargo conditions—heightens the risk, necessitating robust protective measures like encryption and real-time monitoring of network security.

- High initial costs

The second theme centered on the substantial upfront costs associated with IoT adoption, a challenge particularly acute for smaller firms. Eight of the 10 experts pointed out that the investment required for IoT infrastructure—sensors, software platforms, and integration with existing systems—often exceeds the financial capacity of small to medium-sized enterprises (SMEs). One interviewee explained, "For a small operator, spending thousands of dinars on IoT upgrades feels like a gamble when cash flow is tight." This financial burden extends beyond hardware to include training staff and maintaining systems, further straining limited budgets. Larger firms, however, were seen as better equipped to absorb these costs, with one expert noting that "big players can spread the expense across their operations, but SMEs are stuck

waiting for a clear ROI [return on investment].” This disparity underscores a structural barrier to widespread IoT uptake in the sector.

- Lack of standardized protocols impeding integration

The third theme highlighted the absence of standardized protocols as a significant obstacle to seamless IoT integration across transportation networks. Nine experts cited interoperability issues, where differing IoT systems and vendor-specific technologies complicate data sharing and system linkage. A memorable quote captured this frustration: “Without common standards, linking systems across companies is a nightmare—you’re patching together a puzzle with missing pieces.” For instance, one expert described a scenario where a firm’s IoT tracking system couldn’t sync with a partner’s warehouse management software, leading to manual data entry and delays. This lack of uniformity not only slows operational efficiency but also increases costs as firms invest in custom solutions or workarounds to bridge these gaps.

- Validation through case Studies

These themes were mirrored and substantiated by the analysis of three logistics firms’ experiences with IoT implementation. The first case, a mid-sized regional carrier, reported a 12% reduction in delivery delays after deploying IoT-enabled GPS trackers, attributing this gain to real-time route optimization. However, the firm also faced a cyberattack that disrupted its tracking system for 48 hours, reinforcing the cybersecurity theme. The second case, a small logistics provider, achieved modest efficiency gains (e.g., 8% faster inventory updates) but struggled with the 100,000 TND initial cost of IoT hardware, delaying full adoption. The third case, a large multinational firm, showcased a 15% improvement in fleet utilization through predictive maintenance but noted ongoing challenges in integrating its IoT platform with suppliers’ diverse systems, spending an additional 10% of its budget on bespoke integrations. These cases collectively demonstrated tangible benefits—such as reduced delays and improved resource use—while underscoring persistent hurdles in security, affordability, and technical compatibility, aligning closely with the experts’ perspectives.

5. Discussion

The findings illuminate IoT’s transformative role in transportation operations while highlighting areas requiring careful attention. The quantitative results align with prior research, such as McFarlane and al. (2003), who reported similar cost savings from real-time monitoring. The 18% cost reduction and 10-15% improvement in delivery times underscore IoT’s capacity to optimize resource use, echoing Lee and Lee’s (2015) findings on operational efficiency. However, this study extends beyond these benefits by emphasizing predictive maintenance as a critical driver, a point also raised by Elkateb and al. (2024). This capability not only cuts costs but also enhances equipment longevity, offering a dual economic and operational advantage.

Qualitatively, the emphasis on cybersecurity aligns with Niyato and al. (2017), who warned of heightened risks in IoT-enabled systems. The experts’ concerns—supported by 45% of survey respondents flagging security issues—suggest that without robust safeguards, IoT’s benefits could be undermined. Similarly, the high costs and integration challenges resonate with Ur Ur

Rehman and al. (2024), particularly for SMEs, which may struggle to adopt IoT without external support. Unlike Zrelli and Rejeb (2019), who focused heavily on visibility, this study reveals a broader spectrum of benefits and barriers, providing a more holistic view of IoT's impact.

These results carry practical implications. The strong statistical link between infrastructure investment and cost savings ($p < 0.001$) suggests that firms prioritizing IoT hardware may see rapid returns, though integration remains equally vital. Conversely, the qualitative data urge caution, highlighting the need for standardized protocols and cybersecurity measures to ensure scalability. Compared to Sallam and al. (2023), who emphasized sustainability, this study prioritizes operational gains but acknowledges environmental benefits as a byproduct of efficiency. The discussion thus bridges empirical evidence with real-world challenges, offering a nuanced perspective on IoT adoption in transportation logistics.

6. Conclusion

This study provides a comprehensive examination of the Internet of Things (IoT) and its transformative potential in facility supply chain management within transportation operations. The findings confirm that IoT technologies significantly enhance operational efficiency, visibility, and cost-effectiveness, aligning with the research objective to assess their impact in this domain. Specifically, the evidence supports the hypotheses that investment in IoT infrastructure reduces operational costs—demonstrated by an average 18% decrease—and that system integration improves transparency and efficiency, as seen in reduced delivery times and enhanced tracking capabilities. These outcomes highlight IoT's capacity to streamline logistics through real-time monitoring and predictive maintenance, offering tangible benefits to transportation firms.

However, the research also reveals critical challenges that temper these advantages. Cybersecurity risks, high implementation costs, and integration complexities emerged as persistent barriers, necessitating strategic solutions to ensure IoT's full potential is realized. This dual perspective—balancing opportunities with obstacles—enriches the ongoing discourse on IoT's role in supply chain innovation. By combining quantitative data, qualitative insights from experts, and real-world case studies, this paper bridges theoretical promise with practical application, contributing a nuanced understanding to the field.

For industry practitioners, these findings underscore the importance of proactive measures. Investing in robust cybersecurity frameworks and pursuing standardized IoT protocols can mitigate risks and facilitate adoption, particularly for small and medium-sized enterprises (SMEs) constrained by limited resources. Policymakers might consider incentives, such as subsidies or collaborative platforms, to support broader uptake among smaller firms. Looking ahead, researchers are encouraged to pursue longitudinal studies to evaluate IoT's sustained impact on supply chain performance over time, especially in response to disruptions like pandemics or geopolitical shifts. Further exploration of tailored solutions for SMEs, as well as the integration of IoT with emerging technologies like artificial intelligence, could unlock new avenues for creating resilient, intelligent transportation systems. This study thus serves as both

a foundation and a call to action, advancing the conversation on IoT's role in shaping the future of logistics.

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