

# Technical Complexity and Compatibility as Determinants of Artificial Intelligence Adoption in Cold Chain Logistics SMEs: The Mediating Role of Perceived Usefulness

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## Abstract

Artificial intelligence (AI) is widely regarded as a transformative technology in logistics; however, adoption among cold-chain logistics small and medium-sized enterprises (SMEs) remains limited despite the sector's high operational demands and potential performance gains. Prior research has predominantly emphasised organisational readiness and environmental pressures, while giving comparatively less attention to the technological conditions shaping adoption decisions in SME contexts. This conceptual paper develops a focused model to explain AI adoption in cold-chain logistics SMEs by examining technical complexity and technical compatibility as key technological determinants, with perceived usefulness positioned as a mediating mechanism. Drawing on Diffusion of Innovations theory and the Technology Acceptance Model, the framework theorises how complexity and compatibility shape managers' evaluations of AI usefulness, which in turn influence adoption intentions. Synthesising recent literature on AI-enabled cold-chain applications such as predictive temperature analytics and real-time anomaly detection, the paper demonstrates that technological determinants are particularly salient in data-intensive and risk-sensitive environments. By explicitly positioning technical complexity and compatibility as antecedents of perceived usefulness, the study offers a refined theoretical explanation of AI adoption and provides practical insights for improving AI uptake among cold-chain logistics SMEs.

**Keywords:** Artificial Intelligence Adoption, Cold Chain Logistics, Technical Complexity, Technical Compatibility, Perceived Usefulness

## Introduction

### *Background of the Study*

Artificial intelligence (AI) has emerged as a key enabling technology reshaping logistics operations by transforming how goods are transported, tracked, and managed across increasingly complex supply-chain networks (Zhu, 2024; Hossain et al., 2025). When integrated with the Internet of Things (IoT), big data analytics, and cloud computing, AI enables logistics systems to shift from reactive, human-controlled operations toward predictive and autonomous decision-making. In cold-chain logistics, where product quality

and safety depend on precise control of temperature, humidity, and transportation conditions, these capabilities are especially critical. Evidence-based studies show that AI-enabled optimisation tools can significantly reduce spoilage, energy consumption, and operational uncertainty, particularly for goods requiring strict temperature control throughout distribution (Nozari et al., 2025). As global demand for safe and reliable perishable products continues to rise, AI is increasingly viewed as essential for improving supply-chain visibility, meeting regulatory requirements, and supporting sustainability objectives (Xiao et al., 2024; Hossain et al., 2024).

Despite these advantages, AI adoption remains uneven across logistics firms. Large enterprises are better positioned to deploy AI-powered control towers, predictive analytics, and automated warehousing due to stronger financial capacity, specialised expertise, and more established digital infrastructures (Kelly, 2024). In contrast, small and medium-sized logistics enterprises often face tighter resource constraints, limiting their ability to implement comparable systems. Prior research indicates that many SMEs continue to rely on fragmented digital tools and legacy technologies, which constrain the effective use of advanced AI applications. Although cloud-based and modular AI solutions have lowered some entry barriers, challenges related to interoperability, real-time data integration, and alignment with existing processes persist (Joel et al., 2024; Hossain et al., 2023).

These challenges are particularly pronounced in cold-chain logistics, one of the most technologically demanding segments of the industry. Cold-chain operations require uninterrupted data flows, continuous monitoring, and timely automated responses, placing high demands on system reliability and technological compatibility. In China, national initiatives promoting “smart logistics” and the “Digital China” strategy, together with rising food-safety expectations and stricter regulations, have accelerated cold-chain market growth (Zhang et al., 2022). Zhejiang Province exemplifies this development, combining strong policy support with a high concentration of cold-chain SMEs. Nevertheless, evidence suggests that many Zhejiang-based SMEs still rely on manual temperature checks and partially deployed digital monitoring platforms, limiting their ability to scale AI applications and achieve substantial efficiency gains (Sun et al., 2019).

Cold-chain logistics also exhibits distinctive technological characteristics that differentiate it from conventional logistics and manufacturing. The sector depends on tightly connected system components, continuous data streams, and strict operational conditions related to temperature control and product integrity. AI systems must therefore integrate seamlessly with refrigeration equipment, storage facilities, transport vehicles, and IoT-based monitoring devices (Nozari et al., 2025). When such technologies are perceived as overly complex or difficult to integrate, evaluations of AI usefulness decline, reducing adoption likelihood. These conditions underscore the importance of examining technological factors, particularly technical complexity and technical compatibility, as well as perceived usefulness, in understanding AI adoption decisions in cold-chain logistics SMEs (Kelly, 2024).

### **Problem Statement**

Although artificial intelligence adoption has progressed rapidly among large logistics firms, logistics SMEs continue to face significant technological barriers that constrain effective implementation. Key challenges include system sophistication, data-integration

requirements, and misalignment between AI tools and existing operations (Kelly, 2024). Technical complexity is repeatedly identified as a major inhibitor, as many SMEs lack the expertise needed to manage analytics-intensive and sensor-based systems (Eyo-Udo, 2024; Hossain et al., 2022). These constraints are particularly critical in cold-chain logistics, where continuous monitoring and predictive coordination are essential, thereby heightening perceived implementation risk and discouraging adoption (Zhang et al., 2022).

Technical compatibility represents another important but underexplored barrier. Although compatibility is widely recognised in innovation research, it remains insufficiently examined in logistics contexts, especially in cold-chain AI adoption (Pan & Liu, 2021). Many cold-chain SMEs rely on legacy refrigeration systems and fragmented monitoring technologies, complicating integration and limiting feasibility. The limited consideration of compatibility in existing models constrains understanding of how SMEs evaluate AI integration practicality (Sun et al., 2019; Azmi Mohd Ariffin et al., 2026).

Additionally, while perceived usefulness is central to the Technology Acceptance Model, limited research investigates how technological characteristics such as complexity and compatibility shape usefulness perceptions in cold-chain SMEs. Existing studies predominantly emphasise organisational and environmental factors, offering limited insight into the cognitive mechanisms linking technological attributes to adoption.

Collectively, these gaps highlight the need for a framework integrating technical complexity, technical compatibility, and perceived usefulness to explain AI adoption in cold-chain logistics SMEs. Such integration advances theoretical understanding and supports more effective adoption strategies in this technologically intensive sector.

### **Limitations**

As a conceptual paper, this study is inherently theoretical and does not provide empirical validation of the proposed relationships. Although the framework integrates constructs from Diffusion of Innovation theory and the Technology Acceptance Model, the hypothesised mediating role of perceived usefulness and the effects of technical complexity and compatibility remain to be tested using primary data. Consequently, the explanatory power and generalisability of the model cannot be confirmed until future empirical investigation is conducted. In addition, the framework focuses primarily on technological attributes and cognitive evaluation mechanisms, while other potentially influential dimensions such as organisational readiness, leadership support, regulatory pressures, and resource constraints are not explicitly incorporated. This intentional theoretical delimitation enhances conceptual clarity but may limit the comprehensiveness of the adoption explanation in complex real-world settings. Finally, the proposed model is situated within the context of cold chain logistics SMEs, which may restrict its applicability to larger firms or different industry environments without contextual adaptation.

### **Literature Review**

#### *Technological Determinants of AI Adoption in Logistics and Cold-Chain SMEs*

Artificial intelligence (AI) has become a core enabling technology in logistics, transforming forecasting, routing, warehouse automation, and real-time supply-chain visibility (Richey Jr. et al., 2023). In cold-chain logistics, where product safety depends on continuous

temperature control, AI supports temperature prediction, spoilage-risk forecasting, predictive maintenance, and anomaly detection, improving stability, reducing waste, and strengthening regulatory compliance (Habazin, 2025; Li et al., 2025). However, adoption among cold-chain SMEs remains limited. Implementing AI requires tight integration of sensors, analytics platforms, and operational workflows, creating substantial technical demands that are often perceived as challenging in real-time, data-intensive environments (Protopappas et al., 2025; Williams, 2024; Shehzad, 2025). Compared with large firms, SMEs face greater difficulty managing interoperability and aligning AI with existing systems (Schwäke et al., 2025; Ayinaddis, 2025; Islam et al., 2025).

Innovation research highlights that adoption decisions are shaped by technological characteristics. Rogers (2003) and the Technology–Organization–Environment framework identify technical complexity and technical compatibility as central determinants influencing perceived risk, cognitive effort, and strategic fit. Empirical studies across digitalisation and AI confirm that these attributes significantly affect evaluations of usefulness and feasibility, particularly in logistics SMEs (Badghish & Soomro, 2024; Sánchez et al., 2025; Urus et al., 2024).

In cold-chain contexts, these determinants are especially salient due to system interdependence and operational sensitivity. AI must integrate seamlessly with sensor networks, refrigeration systems, and transport platforms, where limited compatibility can compromise reliability and data integrity (Loisel et al., 2022; Lim et al., 2022). Simultaneously, the algorithmic and multi-component nature of AI heightens perceived complexity. Building on the Technology Acceptance Model and diffusion perspectives, this study proposes a technology-centric framework explaining how complexity and compatibility shape perceived usefulness and AI adoption intentions in cold-chain SMEs.

### *Technical Complexity*

Technical complexity is defined as the extent to which an innovation is perceived as difficult to understand and use (Rogers, 2003). In digital transformation contexts, this extends to integration challenges, algorithmic opacity, extensive data requirements, and ongoing maintenance demands (Gillespie). Thus, perceived complexity reflects both cognitive difficulty and operational burden. Prior research consistently reports a negative relationship between perceived complexity and technology adoption (Sahin, 2006; Park, 2022; Overbye-Thompson et al., 2025; Islam et al., 2025).

In AI adoption among SMEs, complexity is particularly influential. Managers often view AI systems as difficult to implement and dependent on specialised expertise, high-quality data, and coordinated integration (Robbins et al., 2024; Badghish & Soomro, 2024; Sánchez et al., 2016). Such perceptions increase uncertainty and implementation risk, weakening adoption intentions. Studies across digital marketing, education technologies, and big data analytics similarly confirm that high perceived complexity discourages adoption, even when benefits are recognised (Ahmed, 2025; Almaiah et al., 2022; Babalghaith et al., 2024; Nur et al., 2024). Objectively, complex technologies involve multiple interdependent components and knowledge domains (Rycroft & Kash, 1999; Broekel, 2019). AI-enabled cold-chain systems exemplify this, requiring continuous IoT data, predictive modelling, and coordinated warehousing and transport responses (Protopappas et al., 2025; Lim et al., 2022; Williams,

2024). In temperature-sensitive environments, perceived fragility and integration difficulty heighten operational risk and weaken perceived usefulness. Accordingly, this study positions technical complexity as a central determinant of perceived usefulness and AI adoption intention in cold-chain logistics SMEs.

#### *Technical Compatibility*

Technical compatibility, derived from Rogers' diffusion of innovations theory, refers to the extent to which a technology aligns with an organisation's existing systems, experience, and operational practices. In logistics contexts, it reflects how well new technologies integrate with current hardware, software, data structures, and workflows. Prior research shows that technologies perceived as compatible are implemented more smoothly, as firms face fewer disruptions, lower integration costs, and reduced uncertainty (Sánchez et al., 2025; Badghish & Soomro, 2024; Hossain et al., 2024).

Compatibility is particularly critical in SMEs, where adoption depends on embedding new systems into daily operations without disruption. In cold-chain logistics, AI must integrate with IoT sensors, refrigeration controls, telematics devices, and warehouse platforms (Protopappas et al., 2025; Lim et al., 2022). Inconsistent data formats or misaligned workflows can undermine system reliability. Empirical studies indicate that implementation challenges often arise from system incompatibility rather than algorithmic limitations (Habazin, 2025; Li et al., 2025), and effective integration is essential for regulatory compliance and real-time responsiveness (Hernández, 2018).

Compatibility also influences perceived usefulness. When AI aligns with existing workflows, learning effort decreases and operational benefits become more visible (Rawashdeh et al., 2023; Lim, 2024). Despite its importance, compatibility remains underexplored in cold-chain AI research (Loisel et al., 2022; Nan et al., 2025). Accordingly, this study positions technical compatibility as a key determinant shaping perceived usefulness and AI adoption decisions in cold-chain logistics SMEs.

#### *Perceived Usefulness*

Perceived usefulness (PU), a central construct of the Technology Acceptance Model, refers to the degree to which individuals believe that using a system enhances job performance (Giancoli, 2018). In logistics research, PU represents the key cognitive link between technological characteristics and adoption behaviour, reflecting managers' evaluations of whether AI improves efficiency, reduces waste, enhances visibility, and supports regulatory compliance.

PU is shaped by technological attributes, particularly technical complexity and compatibility. Technologies that integrate smoothly with existing workflows are more likely to be viewed as useful because they deliver performance gains without excessive cognitive or operational burden (Sánchez et al., 2025; Rawashdeh et al., 2023). Conversely, high perceived complexity weakens usefulness evaluations, as SMEs anticipate implementation and maintenance challenges (Badghish & Soomro, 2024; Ahmed, 2025; Hossain et al., 2024). Thus, PU reflects both expected benefits and perceived feasibility.

In cold-chain logistics, usefulness depends on sector-specific outcomes such as temperature stability, spoilage reduction, route optimisation, and compliance support (Williams, 2024; Shehzad, 2025). Although studies confirm that PU mediates AI adoption in logistics contexts (Frikha & Mrad, 2025; Samuels, 2025), its mediating role in cold-chain SMEs remains underexplored (Habazin, 2025; Li et al., 2025). Accordingly, PU is positioned as the central mechanism linking technological determinants to AI adoption intentions.

### *AI Adoption in Cold-Chain SMEs*

AI adoption is increasingly important in logistics for improving forecasting, routing, anomaly detection, and operational decision-making. Yet SMEs adopt AI more slowly than large firms, largely due to uncertainty about feasibility, perceived technological risk, and the demanding nature of AI systems (Ayinaddis, 2025; Schwäke et al., 2025). These barriers are amplified in cold-chain logistics, where temperature-sensitive operations require continuous monitoring and tightly coordinated systems. Although AI has demonstrated value in reducing waste and enhancing compliance (Protopappas et al., 2025; Williams, 2024; Shehzad, 2025), SME adoption remains uneven.

In cold-chain environments, AI must integrate sensors, refrigeration systems, telematics, and analytics platforms, increasing perceived complexity and operational risk. Managers may recognise potential benefits but hesitate due to concerns about reliability, disruption, and limited interpretative capacity (Mathagu, 2024; Schwäke et al., 2025). Evidence from other SME contexts shows that adoption is delayed until technologies are considered manageable within existing operations (Rawashdeh et al., 2023; Lim, 2024; Haq et al., 2025).

Despite established performance gains, research has paid limited attention to how technological attributes shape managers' cognitive evaluations. In particular, the influence of technical complexity and compatibility on perceived usefulness remains underexplored in cold-chain SMEs (Mustafa, 2024; Habazin, 2025). Grounded in the Technology Acceptance Model, this study addresses this gap by examining how these technological determinants shape perceived usefulness and, in turn, AI adoption decisions.

### **Theoretical Foundation**

A coherent theoretical foundation is essential for explaining how technological characteristics shape AI adoption in cold-chain logistics SMEs. This study draws on two complementary perspectives: Diffusion of Innovations (DOI) and the Technology Acceptance Model (TAM). DOI explains how inherent technological attributes influence adoption behaviour, while TAM clarifies how users' cognitive evaluations, particularly perceived usefulness, translate these attributes into adoption intentions. Together, these theories provide a structured and empirically grounded basis for analysing AI adoption in technologically demanding cold-chain environments.

Within DOI, technical complexity and technical compatibility are especially relevant. Technical complexity refers to the perceived difficulty of understanding, implementing, and operating a technology, which can increase uncertainty and reduce confidence in adoption. In cold-chain logistics, where operational continuity and precise environmental control are critical, such perceptions are particularly consequential. Technical compatibility describes the degree to which a technology aligns with existing systems, workflows, and technological practices.

When AI solutions fit poorly with current operations, integration risks increase, making adoption less likely. These attributes therefore serve as appropriate technological antecedents in the present framework.

While DOI explains why technological characteristics matter, it does not fully account for how these characteristics shape adoption decisions. TAM is therefore incorporated to explain the cognitive mechanism underlying adoption behaviour. TAM identifies perceived usefulness as the primary determinant of intention, reflecting the extent to which users believe a technology will enhance performance. In cold-chain logistics, usefulness is expressed through improved temperature control, reduced spoilage, enhanced traceability, and stronger regulatory compliance. Importantly, TAM conceptualises perceived usefulness as a mediating mechanism through which technological attributes influence adoption intentions, making it well suited for this study.

By integrating DOI and TAM, this study proposes a unified explanation in which technological attributes influence cognitive evaluations, which in turn shape adoption behaviour. This integration aligns with broader digitalisation research in SMEs, where perceptions of technological fit and cognitive burden play decisive roles in adoption outcomes. Given the operational sensitivity and technological interdependence of cold-chain logistics, these relationships are expected to be particularly pronounced. Accordingly, DOI and TAM together provide a robust and contextually appropriate foundation for the conceptual framework developed in this study.

Table 3.1

*Summary of Theoretical Foundations and Supported Variables*

Construct	Definition Focus	Supporting Theory	Core Theoretical Logic
Technical Complexity (IV1)	Perceived difficulty of understanding, integrating, and operating AI systems	Diffusion of Innovations (Complexity)	Higher perceived difficulty increases uncertainty and cognitive burden, reducing adoption likelihood.
Technical Compatibility (IV2)	Degree of alignment between AI systems and existing technologies, workflows, and processes	Diffusion of Innovations (Compatibility)	Greater alignment reduces integration risk and facilitates adoption decisions.
Perceived Usefulness (Mediator)	Belief that AI enhances operational efficiency and cold-chain performance	Technology Acceptance Model (Usefulness)	Usefulness mediates the effects of technological attributes on adoption intention.
AI Adoption (DV)	Intention to adopt and use AI within cold-chain SME operations	Technology Acceptance Model	Adoption behaviour is driven by positive cognitive evaluations of usefulness.

**Research Questions**

Based on the proposed framework, the study addresses the following research questions:

RQ1: What is the relationship between technical complexity and perceived usefulness of artificial intelligence among cold chain logistics SMEs?

- RQ2: What is the relationship between technical compatibility and perceived usefulness of artificial intelligence among cold chain logistics SMEs?
- RQ3: What is the relationship between perceived usefulness and artificial intelligence adoption intention among cold chain logistics SMEs?
- RQ4: Does perceived usefulness mediate the relationship between technical complexity and artificial intelligence adoption intention among cold chain logistics SMEs?
- RQ5: Does perceived usefulness mediate the relationship between technical compatibility and artificial intelligence adoption intention among cold chain logistics SMEs?
- RQ6: How does the proposed integrated framework explain artificial intelligence adoption intention in cold chain logistics SMEs?

### **Research Objectives**

This conceptual paper seeks to develop and clarify a technology focused explanation of artificial intelligence adoption in cold chain logistics SMEs by integrating Diffusion of Innovation theory and the Technology Acceptance Model. Specifically, the study aims:

- RO1: To examine the relationship between technical complexity and perceived usefulness of artificial intelligence among cold chain logistics SMEs.
- RO2: To examine the relationship between technical compatibility and perceived usefulness of artificial intelligence among cold chain logistics SMEs.
- RO3: To examine the relationship between perceived usefulness and artificial intelligence adoption intention among cold chain logistics SMEs.
- RO4: To evaluate the mediating role of perceived usefulness in the relationship between technical complexity and artificial intelligence adoption intention among cold chain logistics SMEs.
- RO5: To evaluate the mediating role of perceived usefulness in the relationship between technical compatibility and artificial intelligence adoption intention among cold chain logistics SMEs.
- RO6: To develop an integrated conceptual framework that explains artificial intelligence adoption intention in cold chain logistics SMEs from a technology attribute and cognitive evaluation perspective.

### **Research Hypotheses**

Drawing upon Diffusion of Innovation theory and the Technology Acceptance Model, this study proposes that technological attributes influence artificial intelligence adoption intention through cognitive evaluation mechanisms. Specifically, technical complexity and technical compatibility are expected to shape managers' perceptions of usefulness, which in turn drive adoption intention. Perceived usefulness therefore functions as the central explanatory mechanism linking innovation characteristics to behavioural intention within cold chain logistics SMEs. Based on the proposed framework, the following hypotheses are formulated:

- H1: Technical complexity has a negative relationship with perceived usefulness of artificial intelligence in cold chain logistics SMEs.
- H2: Technical compatibility has a positive relationship with perceived usefulness of artificial intelligence in cold chain logistics SMEs.
- H3: Perceived usefulness has a positive relationship with artificial intelligence adoption intention in cold chain logistics SMEs.

H4: Perceived usefulness mediates the relationship between technical complexity and artificial intelligence adoption intention in cold chain logistics SMEs.

H5: Perceived usefulness mediates the relationship between technical compatibility and artificial intelligence adoption intention in cold chain logistics SMEs.

The proposed relationships among organisational readiness, external support, employee adaptability, and AI adoption are summarised in the conceptual framework presented in Appendix A (Figure A1).

### **Research Methodology**

This study adopts a quantitative research design to empirically examine the proposed conceptual framework. A cross-sectional survey method is recommended because the objective is to test hypothesised relationships among technical complexity, technical compatibility, perceived usefulness, and artificial intelligence adoption intention within cold chain logistics SMEs. The unit of analysis is the organisation, with data collected from managers and decision makers who are directly involved in evaluating or implementing artificial intelligence technologies. Data would be gathered using a structured questionnaire adapted from established technology adoption literature and contextualised to artificial intelligence applications in cold chain logistics operations. All constructs would be measured using multi-item scales on a five-point Likert format ranging from strongly disagree to strongly agree. Prior to full scale data collection, a pilot study is advisable to ensure clarity of wording and to assess preliminary reliability and validity. Ethical considerations such as voluntary participation, confidentiality, and informed consent would be observed throughout the data collection process.

### **Data Analysis Plan**

The analysis is planned in two sequential stages to ensure methodological rigour. First, preliminary statistical procedures will be conducted to screen the dataset for missing values, outliers, and data entry errors. Descriptive statistics will be generated to summarise respondent and firm characteristics. Internal consistency reliability will initially be assessed using Cronbach's alpha. Following data screening, Structural Equation Modelling using Partial Least Squares will be employed to test the proposed relationships. The measurement model will be evaluated to confirm reliability and validity of the constructs, after which the structural model will be examined to assess the hypothesised direct and mediating relationships. Bootstrapping techniques will be applied to determine the statistical significance of path coefficients and indirect effects.

### **Data Analysis**

SPSS were utilised for initial data preparation, including descriptive analysis and reliability assessment. SmartPLS will then be employed to conduct Partial Least Squares Structural Equation Modelling, which is appropriate for predictive research and mediation testing involving multiple latent constructs. The measurement model evaluation will include assessment of composite reliability, indicator loadings, and average variance extracted to establish convergent validity, as well as the Fornell Larcker criterion and heterotrait monotrait ratio to confirm discriminant validity. Upon satisfactory measurement model results, the structural model will be assessed by examining path coefficients, coefficient of determination, and effect sizes. The mediating role of perceived usefulness will be evaluated using bootstrapped confidence intervals to determine the significance of indirect effects. This

analytical approach enables comprehensive empirical testing of the proposed framework and provides statistical evidence supporting the integration of technological attributes and cognitive evaluation mechanisms in explaining artificial intelligence adoption intention.

### **Finding and Conclusion**

As a conceptual study, the primary finding of this research lies in the development of a theoretically integrated framework explaining artificial intelligence adoption intention in cold-chain logistics SMEs through technological determinants and cognitive evaluation mechanisms. Synthesising Diffusion of Innovations theory and the Technology Acceptance Model, the study clarifies that technological attributes do not operate in isolation. Rather than directly determining adoption decisions, technical complexity and technical compatibility shape managerial evaluations of usefulness, which subsequently influence behavioural intention.

The framework conceptually demonstrates that in technologically interdependent and operationally sensitive environments such as cold-chain logistics, perceptions of system difficulty and integration alignment are central to adoption deliberations. Technical complexity increases cognitive burden and perceived implementation risk, thereby weakening perceived usefulness. Conversely, technical compatibility strengthens usefulness evaluations by reducing integration uncertainty and reinforcing operational feasibility. Perceived usefulness therefore functions as the core explanatory bridge between structural technological conditions and adoption intention, reinforcing TAM's behavioural logic while extending DOI into a highly specialised logistics context.

Importantly, the study highlights that AI adoption barriers in cold-chain SMEs are not solely resource-driven but are strongly influenced by how managers interpret technological fit and operational impact. This conceptual insight advances AI adoption literature by shifting analytical focus from organisational readiness and environmental pressures toward technology-specific determinants and cognitive mechanisms within SMEs operating under high reliability requirements. By positioning perceived usefulness as the mediating mechanism, the framework provides a structured explanation for why adoption may remain limited despite documented performance advantages.

In conclusion, this paper contributes to AI and logistics research by offering a technology-centred explanatory model grounded in established theory and tailored to cold-chain logistics SMEs. The integration of DOI and TAM provides conceptual clarity regarding how innovation attributes translate into behavioural intention under conditions of operational risk and system interdependence. While empirical validation remains necessary, the framework establishes a robust theoretical foundation for future quantitative testing and offers guidance for improving AI uptake through enhanced technological alignment and strengthened value perception.

### **Recommendation**

Based on the proposed framework, several recommendations can be advanced to support artificial intelligence adoption in cold-chain logistics SMEs. At the organisational level, managers should prioritise reducing perceived technical complexity and enhancing technical compatibility before large-scale implementation. This may involve adopting modular or cloud-

based AI solutions that allow phased integration, investing in targeted managerial and employee training, and engaging external technical expertise to minimise implementation uncertainty. Conducting systematic compatibility assessments to evaluate alignment between AI systems and existing refrigeration equipment, IoT sensors, telematics devices, and warehouse management platforms can further reduce operational disruption. By proactively managing complexity and compatibility, SMEs can strengthen perceived usefulness and improve adoption readiness.

At the industry and policy level, technology vendors and public institutions play an important role in facilitating adoption. AI developers should design interoperable, SME-oriented solutions supported by integration guidance, transparent system interfaces, and ongoing technical assistance. Policymakers and industry associations can support cold-chain SMEs through digital transformation grants, standardisation initiatives that promote interoperability, and sector-specific training programmes. Demonstration projects and pilot implementations that provide measurable evidence of operational improvements, such as spoilage reduction and enhanced temperature stability, may further reinforce perceived usefulness and encourage wider AI uptake across the cold-chain sector.

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