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The implications of blockchain for logistics operations and sustainability

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A B S T R A C T

Empirical studies based on detailed, theory-based analyses are essential for a deep understanding of technology adoption. This study provides an overview of blockchain applications in logistics management, employing a comprehensive theoretical framework. Blockchain is considered a critical digital infrastructure for logistics operations due to its distinctive characteristics, including decentralization, transparency, immutability, real-time information sharing, reliability, and end-to-end visibility. These characteristics address many contemporary logistics challenges. The study introduces a research model that integrates the fit-viability model (FVM) and task technology fit theory (TTF), demonstrating blockchain's suitability for enhancing logistics operational functions and sustainability performance. To validate the model, data were collected from logistics managers of 576 companies and analyzed using partial least squares (PLS) regression. This research offers valuable insights for managers, policymakers, and decision-makers on practical challenges and potential solutions in logistics through the application of blockchain. Furthermore, the study demonstrates that the implementation of blockchain can improve the alignment, resilience, transparency, integration, and sustainability of logistics tasks.

Introduction

Digital transformation is pivotal in shaping the dynamic business landscape, particularly in supply chain operations and logistics. Blockchain is viewed as a revolutionary digital infrastructure within the supply chain management (SCM) literature (Ahmed, MacCarthy, & Treiblmaier, 2022), noted for its distinctive features such as decentralization, transparency, immutability, real-time information dissemination, reliability, and end-to-end visibility. These features facilitate novel approaches to addressing challenges within logistics and the supply chain (Ahmed & MacCarthy, 2023; Aslam, Saleem, & Kim, 2023a; Jum'a, 2023).

The SCM sector has recently shown increasing interest in adopting blockchain solutions, although their implementation is still at an early stage (Durach, Blesik, von Düring, & Bick, 2021; Gligor et al., 2022), and restrained by a lack of empirical studies investigating blockchain implementations in logistics (Aslam, Saleem, Khan, & Kim, 2021; Karakas, Acar, & Kucukaltan, 2021). Over the past few decades, logistics practices have faced challenges including data integration, cybersecurity, supply chain complexity, uncertainty, resilience, transparency, collaboration, and real-time information dissemination (Gläser, Jahnke, & Strassheim, 2023; Xu & He, 2022). Blockchain technology has been recommended as a central solution to overcome these challenges by, for example, facilitating the digitalization of logistics operations by providing a secure and immutable platform that improves operational efficiency, transparency, and data integrity (Guo, Chen, Li, Li, & Lu, 2022).

The lack of empirical research on blockchain implementation in logistics leaves the academic community with a deficit of in-depth studies and adoption frameworks. This study introduces an empirical and theoretical model of blockchain adoption in logistics management to address this gap. The study presents an initial framework relating blockchain adoption to specific challenges in logistics management, to aid decision-making by informing about the relevance and application of blockchain technologies. Blockchain provides a secure, decentralized, smart contract-based, transparent, reliable, and immutable platform for real-time information sharing (Omar et al., 2022; Sangari & Mashatan, 2022), offering significant advantages for logistics. This study categorizes the benefits of blockchain for logistics into five main areas: alignment, resilience, transparency, integration, and sustainability (Adhi & Ramanathan, 2022; Iranmanesh et al., 2023; Tan et al., 2023; Zhu, Guo, & Zou, 2022). The implementation of blockchain technology represents

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a revolutionary approach to logistics, with features that promise to enhance logistics efficiency. Blockchain's capabilities include providing immutable, transparent, secure, auditable, and streamlined documentation, which can be used to enhance social responsibility, manage economic variability, and promote environmental sustainability (Mulligan, Morsfield, & Cheikosman, 2023).

Prior research has revealed various ways in which new technologies align with an organization and its environment. Numerous theories have been proposed, including the well-established technology acceptance model (TAM), technology-organization-environment model (TOE), fit-viability model (FVM), unified theory of acceptance and use of technology (UTAUT), and task-technology fit (TTF) (Baker, 2012; Furneaux, 2012; Goodhue & Thompson, 1995; Marangunić & Granić, 2015; Saleem, Aslam, Kim, Nauman, & Khan, 2022; Venkatesh, Thong, & Xu, 2016). This study builds on two relevant theories, TTF and FVM, by examining their utility in understanding logistics managers' intentions toward the adoption of blockchain technologies. TTF evaluates the alignment of a technology with specific tasks; we use TTF to assess blockchain's suitability for effective integration into logistics objectives such as alignment, resilience, transparency, and integration. Viewed through the lens of TTF, blockchain can be considered a sustainable technology fit (STF). TTF facilitates the assessment of blockchain compatibility with logistics sustainability requirements (Oh, Xiao, Park, & Roh, 2023) across social, economic, and environmental contexts. Further insights into the adoption of blockchain are provided by the FVM, which emphasizes factors of feasibility or viability (top management support and technology readiness) and whether firms have the necessary resources for successful implementation (Liang, C, Y, & Lin, 2007, 2021). The novel integration of TTF and FVM in this study's conceptual model represents a significant contribution to logistics research, as this approach has not previously been explored within the logistics context.

This study contributes novel ideas in several ways. First, we emphasize logistics management challenges in modern businesses and propose a blockchain-based framework as a potential solution. This involves exploring blockchain technology's applicable properties and addressing practitioners' and decision-makers' questions regarding the relevance of blockchain. Second, adopting blockchain is a pivotal decision that requires significant capital investment. We demonstrate how the characteristics of blockchain technology are suitable for completing logistics tasks and enhancing sustainable logistics management. Third, we analyze how the FVM helps determine the intention to adopt blockchain and how blockchain-enabled agility influences adoption behavior. Fourth, we provide an empirical analysis for practitioners and decision-makers, aiding their understanding of how logistics managers perceive the benefits of blockchain adoption, particularly in enhancing logistics practices and sustainability.

The rest of the article is organized as follows: Section 2 provides a comprehensive review of the existing literature on digital transformations in logistics, blockchain properties, logistics management challenges, FVM, TTF, STF, viability, and intention to adopt blockchain. This section also outlines the proposed framework and research model. Section 3 describes the study methodology, covering sampling, measures, and data collection. Section 4 focuses on data analysis and presents the results. Section 5 offers a detailed discussion encompassing both theoretical and managerial implications of blockchain adoption. Finally, Section 6 concludes the paper by reflecting on the study's limitations and providing recommendations for future research.

Literature review, theories, and hypotheses development

Digital transformation in logistics

Logistics management continually seeks to establish efficient systems that guarantee robust tracking, traceability, and data privacy for shipments and inventory. In the digital era, technology plays a critical role in addressing complex issues related to SCM and logistics, such as visibility, traceability, and transparency (Gohil & Thakker, 2021; Goldsby & Zinn, 2016; Tiwari, Sharma, Choi, & Lim, 2023). The integration of advanced technologies like the Internet of Things (IoT), Artificial Intelligence (AI), blockchain, robotics, and cloud computing into supply chains and logistics is fundamental to these objectives (Lei & Ngai, 2023; Sung, Bock, & Kim, 2023). It is essential to understand the potential effects of these technologies on logistics, as each technology also exhibits limitations, including security vulnerabilities, centralization issues, scalability challenges, and the tradeoff between immutable and auditable records (Chung, 2021; Cichosz, Wallenburg, & Knemeyer, 2020). Blockchain promises unique benefits to the logistics industry by addressing many of these challenges. Its decentralized and cryptographic architecture offers enhanced security, protection against cyber threats, and data immutability, all of which ensure the integrity of transaction records and data (Awadallah, Samsudin, Teh, & Almazrooie, 2021; Bansal, Panchal, Bassi, & Kumar, 2020; Bodkhe et al., 2020; Gohil & Thakker, 2021). Table 1 encapsulates the fundamental properties, implications, and limitations of various technologies.

Logistics and blockchain

Prior studies have highlighted the role of blockchain in SCM (Fernandez-Vazquez, Rosillo, De la Fuente, & Puente, 2022; Risso et al., 2023; Sauer, Orzes, & Culot, 2022), yet the literature still requires a clearer delineation of blockchain's value creation within logistics, which must be explored through empirical studies; this study aims to establish a connection between logistics operations and blockchain attributes.

Table 1
Summary of digital technologies used in logistics.

Technology	Fundamental properties	Implication	Limitation
Blockchain (Orji, Kusi-Sarpong, Huang, & Vazquez-Brust, 2020; Zhang & Liu, 2023)	Decentralization, cybersecurity, smart contracts, immutability, real-time irrevocable information sharing, transparency, and standardization.	Provides a real-time, tamperproof, transparent, reliable, and visible data management system.	The complexity of implementation and regulatory uncertainty.
IoT (Kumar, Tyagi, & Sachdeva, 2023)	Real-time data collection, connectivity, and exchange.	IoT facilitates real-time data monitoring, enhancing efficiency, automation, and decision-making processes.	Issues include data security, privacy, scalability, data overload, interoperability, and compatibility.
AI (Chien, Dauzère-Pérès, Huh, Jang, & Morrison, 2020; Tsolakis, Zissis, Papaefthimiou, & Korfiatis, 2022)	Capabilities encompass learning, reasoning, and decision-making.	Focus areas include automation, predictive analytics, and optimization.	Challenges pertain to data availability, quality, transparency, and interpretability.
Robotics (Atzeni, Vignali, Tebaldi, & Bottani, 2021; Liu, Hua, Cheng, Choi, & Dong, 2023)	Focuses on automation and execution of physical tasks.	Enables efficient repetitive activities, increasing accuracy and efficiency.	Challenges include limited adaptability, substantial capital investment, and high maintenance costs.
Cloud Computing (Zhang & Liu, 2023)	Offers scalability and unlimited data storage.	Enables seamless collaboration, integration, and data accessibility.	Vulnerable to issues such as high internet dependency, data privacy, and security.

Table 2
Blockchain properties and logistics operations.

Blockchain properties	Blockchain-enabled Logistics	Reference
Decentralization	Decentralization allows authorized supply chain stakeholders to access real-time information directly via a highly secure platform, eliminating the need for intermediaries. This method enhances communication efficiency and improves coordination amongst stakeholders.	(Lin et al., 2022; Sharma et al., 2021)
Real-time information sharing	Real-time information sharing is essential in logistics, as it delivers accurate, current, and immediate data, facilitating timely decision-making and expedited actions.	(Sauer et al., 2022; Treiblmaier et al., 2022)
Data management	Blockchain provides synchronized data across all supply chain partners, offering tamper-proof information and removing discrepancies.	(Patro et al., 2021; Treiblmaier et al., 2022)
Immutability	Immutability ensures data integrity by guaranteeing that information cannot be altered once confirmed. It prevents unauthorized modifications and facilitates proper information flow through the system.	(Aslam, Saleem, Khan, & Kim, 2022; Swain et al., 2021; Treiblmaier et al., 2022)
Smart Contractor	Smart contracts facilitate digitalization and automation, reducing human errors from manual processes and enhancing efficiency.	(Lin et al., 2022; Vyas et al., 2019)
Scalability	Blockchain-based scalability ensures the handling of high transaction volumes without performance degradation, permitting smooth and rapid financial transactions.	(Helo & Shamsuzzoha, 2020)
Auditability	Blockchain's verified ledger maintains data accuracy and integrity, facilitating transparent auditing processes.	(Vyas et al., 2019)
Cyber-security	Blockchain employs advanced cryptographic techniques, creating a highly secure data platform that is virtually impenetrable. This security protects the confidentiality of sensitive logistics information.	(Aslam et al., 2021; Yang et al., 2021)
Trust	Blockchain enhances logistic operations security, enabling stakeholders to depend on data transparency, authenticity, and immutability, thus fostering trust and collaboration.	(Aslam et al., 2022; Fosso Wamba, Kala Kamdjoug, Bawack, & G Keogh, 2018)
Traceability	Blockchain ensures real-time, transparent information that facilitates the traceability of goods throughout the logistics process.	(Queiroz, Telles, & Bonilla, 2019)
Transparency	Blockchain provides a decentralized system that grants all relevant stakeholders access to uniform information. This functionality enhances transparency, fosters trust, and improves collaboration.	(Lin et al., 2022; Treiblmaier et al., 2022)
End-to-end visibility	Blockchain promotes visibility by sharing information in real-time and ensuring transparency, which supports effective collaboration, helps anticipate demand fluctuations, and optimizes inventory management.	(Behnke & Janssen, 2020; Vyas et al., 2019)
Irrevocable information	In the context of blockchain, irrevocable information means that data cannot be altered or deleted without the permission of the relevant participant, thus providing reliability by preventing the tampering or manipulation of information.	(Dilawar et al., 2019; Sharma et al., 2021)
Data privacy	Privacy protection is a key function of blockchain, utilizing its cybersecurity and immutability features to maintain control over sensitive data related to customers, suppliers, inventory, and pricing.	(Arora et al., 2019; Behnke & Janssen, 2020)

Blockchain possesses numerous properties that can enhance the efficiency of logistics processes (Arora, Gautham, Gupta, & Bhushan, 2019; Aslam et al., 2021, 2022, 2023b; Behnke & Janssen, 2020; Dilawar, Rizwan, Ahmad, & Akram, 2019; Helo & Shamsuzzoha, 2020; Lin, Zhang, Li, Ji, & Sun, 2022; Patro, Ahmad, Yaqoob, Salah, & Jayaraman, 2021; Sauer et al., 2022; Sharma, Kaur, & Singh, 2021; Swain, Peter, Adimuthu, & Muduli, 2021; Treiblmaier, Rejeb, & Ahmed, 2022; Vyas, Beije, & Krishnamachari, 2019; Yang, Garg, Huang, & Kang, 2021). Table 2 lists and describes the blockchain properties most relevant for logistics.

Logistics challenges and blockchain

In complex and globalized supply chains, business enterprises encounter numerous challenges in achieving smooth operations, including concerns with data integration, visibility, traceability, information sharing, supply chain complexity, transparency, collaborative communication, data privacy, trust, supply chain disruptions, security, demand uncertainty, standardization, and resilience (Enarsson, 2006; Jagtap et al., 2020; Lai & Cheng, 2016; Montoya-Torres, Muñoz-Villamizar, & Mejia-Argueta, 2023). Considering these challenges, blockchain is viewed as the optimal solution to overcome these difficulties and enhance logistics efficiency (Aslam et al., 2021, 2022; Choi & Siqin, 2022; He et al., 2022). Leveraging blockchain properties can improve decision-making, prevent disruptions, optimize inventory, secure financial transactions, combat counterfeiting, manage high transaction volumes, reduce supply chain complexities, and facilitate communication and collaboration among supply chain participants. Moreover, blockchain ensures data privacy, facilitates accurate and timely demand forecasting, and standardizes processes and systems. Table 3 discusses how blockchain addresses the pressing challenges in SCM and logistics.

Implementing blockchain can address challenges in logistics management across two dimensions. Firstly, enhancing logistics functions such as alignment, resilience, transparency, and integration boosts operational activities. Secondly, logistics processes require upgrades to enhance sustainability in terms of social, economic, and environmental factors. In this context, blockchain-enabled logistics activities can enhance the overall sustainability performance of organizations. Fig. 1 presents a graphical overview that maps blockchain properties to the challenges outlined in Table 3 in order to enhance logistics performance. Each blockchain property is distinguished by a different color in Fig. 1 to indicate the challenges it addresses.

Fit-viability model and task technology fit theory

The FVM is a well-known model used to examine the conditions under which firms adopt a new technology (Liang, Huang, H, & Li, 2021). This study explores the FVM to understand the alignment of logistics tasks with blockchain characteristics, termed tasks-technology fit. It also investigates blockchain's contribution to sustainability to assess the technology's fit with the social, economic, and environmental demands of logistics activities. In FVM, 'fit' refers to the degree to which a new technology's capabilities are appropriate for an organization's tasks and create value in the firm's processes. This concept is derived from the TTF model (Muchenje & Seppänen, 2023). Integrating technology with tasks is deemed crucial for enhancing a firm's capabilities and improving performance. The utilization of blockchain in logistics particularly helps to overcome challenges related to alignment, resilience, transparency, and integration. If a given technology meets the task performance requirements, the firm should assess the technology's viability within the organization. In this study, 'viability' encapsulates the support of top management for blockchain adoption and its readiness for logistics functions. Top management support is essential for adopting new technology as it provides leadership, vision, and decision-making authority crucial for driving the implementation process. Evaluating the readiness of blockchain in logistics entails whether the current technological infrastructure, workforce skills, and processes

Table 3
Mapping of blockchain properties as a solution to challenges.

Logistics challenges	Relevant blockchain properties	Blockchain as a solution	Reference
Data integration	Decentralization, real-time information sharing, data management, auditability, irrevocable information, data privacy, and transparency.	In logistics operations, data integration involves harmonizing and consolidating data from the supply chain process. Blockchain enhances data integration by facilitating decentralization with real-time information and enabling irrevocable, auditable, transparent, and private data management.	(Adere, 2022; Queiroz & Fosso Wamba, 2019)
Visibility	Real-time information sharing, data management, auditability, cyber-security, traceability, and end-to-end visibility.	In the modern era, challenges in logistics visibility include difficulties in obtaining real-time and accurate visibility of goods and information. Blockchain can address these challenges with its capabilities for real-time information sharing, data management, auditability, cyber-security, traceability, and end-to-end visibility. These features ensure accurate and timely information, help prevent disruptions, and optimize logistics process visibility.	(Sahoo, Kumar, Mishra, & Tripathi, 2022; Yoo & Won, 2018)
Traceability	Real-time information sharing, data management, scalability, traceability, and end-to-end visibility.	Logistics traceability issues involve challenges in obtaining accurate and real-time visibility of items and information. Blockchain can address these issues through features such as real-time information sharing, data management, auditability, cyber-security, traceability, and end-to-end visibility.	(Kshetri, 2021; Shahzad, Zhang, Zafar, Ashfaq, & Rehman, 2023)
Information Sharing	Decentralization, real-time information sharing, data management, auditability, scalability, and cyber-security.	Information sharing is a critical aspect of logistics. Due to the complexity of logistics operations, ensuring the flow of accurate and timely information is challenging. Blockchain offers an efficient data management system that supports real-time information sharing and decentralization, handles high transaction volumes, and incorporates auditability and cyber-security.	(Hald & Kinra, 2019; Oliveira-Dias, Moyano-Fuentes, & Maqueira-Marín, 2022)
Supply Chain Complexity	Real-time information sharing, immutability, and transparency.	Logistics is inherently complex due to multiple suppliers, unpredictable demand, varied lead times, and the need for improved coordination among partners. Blockchain smooths logistics operations by enabling real-time information sharing in an immutable and transparent system, thereby reducing supply chain challenges.	(Charles, Emrouznejad, & Gherman, 2023; Khan et al., 2022; Zhu et al., 2022)
Transparency	Real-time information sharing, scalability, auditability, cybersecurity, trust, transparency, and data management.	Challenges in transparency stem from difficulties in achieving clear visibility into movements, relevant data, and status within the logistics process. Blockchain offers a solution through its provision of an auditable, secure, and trusted data management system capable of handling large volumes of data in real time.	(Kshetri, 2021; Yoo & Won, 2018)
Collaboration and Communication	Scalability, decentralization, transparency, data management, real-time information sharing, smart contractors, and trust.	Logistics entails managing multiple activities concurrently, with significant challenges in establishing seamless communication among supply chain members. Blockchain enhances collaboration and communication by providing scalability, decentralization, transparency, data management, real-time information sharing, smart contracts, and trust.	(Agrawal, Angelis, Khilji, Kalaiarasan, & Wiktorsson, 2023; Akhavan & Philsoophian, 2022)
Data Privacy	Cybersecurity, data management, irrevocable information, and data privacy.	Logistics operations generate extensive data, involve multiple parties, and carry high privacy risks and susceptibility to unauthorized access. Blockchain, with its robust features such as cybersecurity, data management, irrevocable information, and heightened data privacy, effectively addresses these security and privacy concerns.	(Longo, Nicoletti, Padovano, d'Atri, & Forte, 2019; Wu et al., 2019)
Trust	Transparency, scalability, immutability, real-time information sharing, auditability, trust, and end-to-end visibility.	Logistics involves multiple partners, making trust among all participants essential. Blockchain features such as transparency, scalability, immutability, real-time information sharing, auditability, trust, and end-to-end visibility are crucial in managing trust.	(Chang & Chen, 2020; Wu & Zhang, 2022)
Supply chain disruptions	Real-time information sharing, decentralization, and end-to-end visibility.	Supply chain disruptions are unforeseen events that interrupt the smooth flow of logistics operations. Blockchain features like real-time information sharing provide valuable up-to-date information for effective visibility in a decentralized system.	(Alkhudary, Queiroz, & Féniès, 2022; Cole, Stevenson, & Aitken, 2019)
Security	Cyber-security, data management, immutability, scalability, auditability, and irrevocable information.	Logistics functions must multitask to handle vast amounts of information and product flow. At each point, the logistics system requires a highly secure structure for managing both information and products. The blockchain provides a data management system that ensures cyber-security, including features such as immutability, scalability, auditability, and irrevocable information, making it resistant to tampering and hacking.	(Kim & Shin, 2019; Queiroz, Telles, & Bonilla, 2020)
Demand uncertainty	Transparency and real-time information sharing.	Demand uncertainty presents a significant challenge in supply chain operations, affecting logistics especially when demand is irregular or intermittent. Blockchain features, including transparency in inventory management and real-time	(Babaei, Khedmati, Akbari Jokar, & Tirkolaee, 2023; Yoon, Talluri, Yildiz, & Sheu, 2020)

(continued on next page)

Table 3 (*continued*)

Logistics challenges	Relevant blockchain properties	Blockchain as a solution	Reference
		information on stock and supply, enable firms to swiftly adapt to unpredictable demand patterns.	
Standardization	Irrevocable information, smart contracts, and data management.	Logistics must standardize processes and systems across multiple partners, customers, and suppliers. Blockchain provides a data management platform using irrevocable information and smart contracts, ensuring the integrity of information, which, once recorded, cannot be altered or modified.	(Banerjee, 2018; Jabbar, Lloyd, Hammoudeh, Adebisi, & Raza, 2021)
Supply chain resilience	Real-time information, traceability, transparency, decentralization, end-to-end visibility, and data management.	Logistics are vulnerable to various risks, including supplier issues, demand uncertainty, and natural disasters. To manage these risks, blockchain provides a reliable system based on real-time information sharing, traceability, transparency, visibility, and updated data management through a decentralized platform.	(Li, Xue, Li, & Ivanov, 2022; Min, 2019)
Last-mile delivery	Real-time information sharing, smart contracts, traceability, transparency, end-to-end visibility, cybersecurity, and data privacy.	Real-time information sharing is crucial in last-mile logistics, where updates are essential for accurate, timely, and efficient delivery. Blockchain provides a secure system based on real-time data sharing and tracking, which enhances the visibility and transparency of delivery operations. Blockchain smart contracts automate processes such as delivery confirmation and payments, reducing errors and manual intervention.	(Chu, Wang, Ren, Li, & Zhang, 2024; Lobo, Wicaksono, & Valilai, 2022)

are geared to support blockchain adoption. This insight into viability underscores the necessity for substantial financial and technical support in adopting new technology (Vekinis, 2023). We analyze the critical FVM factors of fit and viability to comprehend organizations' intentions to adopt blockchain technology for logistics functions.

Hypotheses development

Task-technology fit between logistics tasks and blockchain

In this study, we focus on the challenges encountered in logistics operations and suggest that adopting blockchain properties can address these challenges and enhance overall efficiency. Specifically, we highlight the potential for blockchain to enhance logistics performance in terms of alignment, resilience, transparency, and integration. According to the TTF theory, these tasks are technology-related characteristics that can be improved by implementing blockchain (Ahmed & MacCarthy, 2022). In this study, TTF refers to the compatibility between blockchain properties and logistics tasks, evaluating whether blockchain can effectively support tasks such as alignment, resilience, transparency, and integration in logistics operations (Roth, Stohr, Amend, Fridgen, & Rieger, 2023).

Logistics alignment involves synchronizing and coordinating logistics partners, stakeholders, and firm processes (Salam & Bajaba, 2023). Blockchain provides real-time, updated information that is invaluable for improving communication and collaboration in logistics operations. Moreover, it enhances alignment in logistics operations as the technology improves the accuracy, reliability, and integrity of data, aiding the decision-making process and reducing errors, which in turn boosts alignment-related tasks within logistics functions (Cui, Gaur, & Liu, 2023; Guan, Ding, Zhang, & Verny, 2023). Referring to the TTF, blockchain-enabled alignment is a technology-related characteristic that can significantly improve logistics functions (Mumtaz, Bergey, & Letch, 2024). In summary, we hypothesize that blockchain-enabled alignment positively influences the TTF:

H1. Blockchain-enabled logistics alignment positively impacts the TTF.

Resilience in logistics is defined by the capacity of the logistics activities to resist and recover from supply chain disruptions (Shishodia, Sharma, Rajesh, & Munim, 2023). Blockchain provides end-to-end visibility throughout the entire logistics process, enabling timely monitoring and control of logistics activities to mitigate disruptions. In the event of a disruption, blockchain rapidly identifies the affected products and components, facilitating the timely application of solutions to minimize impact. This is facilitated through smart contracts, which automate the execution and triggering of actions based on predefined conditions (Datta, Jauhar, & Paul, 2023; Pattanayak, Arputham, Goswami, & Rana, 2023). The TTF theory highlights task-specific issues and emphasizes the critical need to align tasks with technology. Thus, logistics resilience benefits from the integration of blockchain technology to manage disruptions and facilitate smooth operations. Consequently, blockchain-enabled logistics resilience aligns tasks and technology more effectively, resulting in superior TTF outcomes. We therefore propose the following hypothesis:

H2. Blockchain-enabled logistics resilience positively impacts the TTF.

Transparency means that a firm is fully aware of all stages of logistics activities, supported by open communication between internal and external participants. The need for logistics to swiftly meet pressing demands necessitates that transparency be prioritized during the real-time assessment of stocks, deliveries, and order scheduling (Morgan, Gabler, & Manhart, 2023). Blockchain enhances logistics transparency by providing visible, traceable, and auditable real-time records of logistics processes on highly secure platforms (Centobelli, Cerchione, Vecchio, Oropallo, & Secundo, 2022). These blockchain technology attributes significantly boost transparency and thus contribute to effective logistics operations. Blockchain-improved transparency in logistics therefore constitutes a high TTF (Han, Shiwakoti, Jarvis, Mordi, & Botchie, 2023; Urman & Makhortykh, 2023). Consequently, we propose the following hypothesis:

H3. Blockchain-enabled logistics transparency positively impacts the TTF.

In logistics, integration refers to the seamless combination and coordination of various logistics processes, systems, and functions, which includes closely aligning both internal and external activities (Wang & Feng, 2023). Through the provision of a unified and interconnected structure, blockchain streamlines the integration of internal and external logistics processes. This architecture ensures the efficient flow of secure, dependable, and precise information. Integration enabled by blockchain leads to modernized operations, reduced costs, enhanced customer satisfaction, and improved overall logistics performance (Long, Feng, Fan, & Liu, 2023). Achieving this integration through blockchain is recognized as a technological characteristic (Queiroz et al., 2020). Within the TTF framework, effective integration in logistics functions fosters exceptional task performance, enhancing TTF. Consequently, we hypothesize that blockchain-facilitated logistics integration significantly enhances TTF:

H4. Blockchain-enabled logistics integration positively impacts the TTF.

Logistics and blockchain as a sustainable technology fit

Sustainability in logistics encompasses practices and processes aimed at enhancing performance across environmental, economic, and social dimensions. For the full enhancement of logistics functions, sustainability must be an integral component (Parhi, Joshi, Gunasekaran, & Sethuraman, 2022). The academic literature indicates that organizations have implemented various initiatives, such as green, sustainable, and circular practices, to advance the sustainability of logistics activities (Shahidzadeh & Shokouhyar, 2023; Sun, Yu, & Solvang, 2022). In this context, blockchain can transform logistics functions by integrating sustainable activities focused on social reforms, economic stability, and environmental protection. In this study, we propose that blockchain has a high STF on account of offering greater visibility, accountability, traceability, immutability, and a decentralized structure. These blockchain features can significantly enhance the overall efficiency of logistics processes in terms of sustainability from social, economic, and environmental perspectives (Rejeb & Rejeb, 2020; Saberi, Kouhizadeh, Sarkis, & Shen, 2019; Sarfraz, Khawaja, Han, Ariza-Montes, & Arjona-Fuentes, 2023).

Logistics management can contribute to social sustainability through various internal and external measures. Internally, firms support social sustainability by ensuring favorable working conditions, providing equal employment opportunities, respecting human rights, and offering fair compensation that promotes the diversity, equity, and inclusion (DEI) framework (Park, Voss, & Voss, 2023). Externally, firms must engage with local communities, enhance their development, and minimize the adverse social impacts of logistics operations (Mani et al., 2016). The transparency, auditability, and trust attributes of blockchain enhance logistics operations and address social issues such as promoting fair labor practices, preventing child labor, and ensuring safe working environments. Moreover, blockchain's automation capabilities facilitate the timely and equitable payment of wages and eliminate intermediaries (Ronaghi & Mosakhani, 2022; Venkatesh, Kang, Wang, Zhong, & Zhang, 2020). Considering blockchain's role in enhancing social sustainability, we propose that effective blockchain-enabled social sustainability leads to higher STF:

H5. Blockchain-enabled social sustainability in logistics positively impacts the STF.

In terms of economic sustainability, logistics operations must sustain long-term economic value without adversely affecting the economic environment. To achieve this, logistics organizations strive to enhance operational efficiency, reduce costs, boost profitability, and contribute to economic growth (Bhattacharjee & Cruz, 2015; Mota, Gomes, Carvalho, & Barbosa-Povoa, 2015). Recognized as both disruptive and innovative, blockchain technology streamlines, automates, and optimizes logistics processes. It also improves the transparency and security of financial transactions, making them more reliable and tamper-proof (Esmaeilian, Sarkis, Lewis, & Behdad, 2020). Blockchain thus enables economic sustainability by accelerating transactions and cutting transaction costs while reducing the necessity for intermediaries (Kouhizadeh, Saberi, & Sarkis, 2021). Therefore, we propose:

H6. Blockchain-enabled economic sustainability in logistics positively impacts the STF.

Environmental sustainability in logistics operations focuses on minimizing adverse environmental impacts associated with the movement, storage, and handling of goods. It involves implementing strategies and measures to reduce carbon emissions, waste generation, energy consumption, and other forms of ecological degradation (Abbasi & Nilsson, 2012; Kumar, Singh, Mishra, & Daim, 2023). Blockchain enhances transparency and traceability, supporting sustainable sourcing and mitigating risks related to illegal or unsustainable practices. Within the STF context, blockchain contributes to environmental sustainability by enabling real-time visibility, tracing, and tracking of products, thereby reducing rework, resource use, and emissions (Biswas, Jalali, Ansaripoor, & De Giovanni, 2023). Consequently, the benefits of adopting blockchain for environmental sustainability lead to an improved STF. Thus, we propose the following hypothesis:

H7. Blockchain-enabled environmental sustainability in logistics positively impacts the STF.

Task-technology fit of blockchain adoption

TTF refers to the alignment between the characteristics of a technology and the tasks it needs to perform. It plays a dual role when evaluating the intention to adopt new technologies, like blockchain, in logistics. First, TTF enables organizations to assess how blockchain can address the specific tasks and needs of their logistics operations. Secondly, by evaluating the compatibility between blockchain's features and the requirements of logistic functions, TTF guides the identification of potential benefits and drawbacks of blockchain adoption (Thakuriya, Kaur, & Mishra, 2023). In this study, TTF assists in verifying if blockchain technology meets the logistical tasks and demands effectively. Moreover, blockchain characteristics such as decentralization, immutability, and transparency contribute to increased trust, security, and accountability (Chaudhuri, Bhatia, Subramanian, Kayikci, & Dora, 2022). Thus, TTF sheds light on the decision to adopt blockchain according to its alignment with the specific tasks and goals of logistics processes. This study proposes that blockchain demonstrating TTF is crucial for understanding the intention to adopt blockchain in logistics, as outlined in the following hypothesis:

H8. Adequate blockchain TTF positively impacts the intention to adopt blockchain.

Sustainable technology fit of blockchain adoption

STF examines the compatibility and alignment between the principles of sustainability and the capabilities offered by blockchain. In logistics, blockchain technology holds significant potential to support sustainability initiative by enabling transparent and immutable recordkeeping, enhancing supply chain traceability, and verifying sustainable practices (Bai & Sarkis, 2020). Organizations can more effectively monitor and validate sustainable sourcing, reduce carbon emissions, and promote ethical practices using blockchain technology. STF evaluates whether the adoption of blockchain technology aligns with sustainability goals, fostering environmentally friendly practices, social responsibility, and long-term economic viability. In this study, STF is a crucial consideration in evaluating the integration of blockchain technology. Therefore, we propose that a high STF significantly influences the intention to adopt blockchain:

H9. A high STF positively impacts the intention to adopt blockchain.

Viability of blockchain adoption

In the FVM model, viability refers to the feasibility of organizations adopting new technologies (Zekhnini, Cherrafi, Bouhaddou, Chaouni Benabdellah, & Raut, 2021). The viability of blockchain adoption is influenced by two primary factors: top management support and technology readiness. Top management support, defined as the assistance and commitment of senior executives toward adopting and implementing blockchain technology, provides the necessary resources, direction, and influence to effectively drive the adoption process (Clohessy & Acton, 2019). Technology readiness, which assesses the organization's preparedness and capability for blockchain adoption, involves evaluating the existing infrastructure, technical expertise, and processes

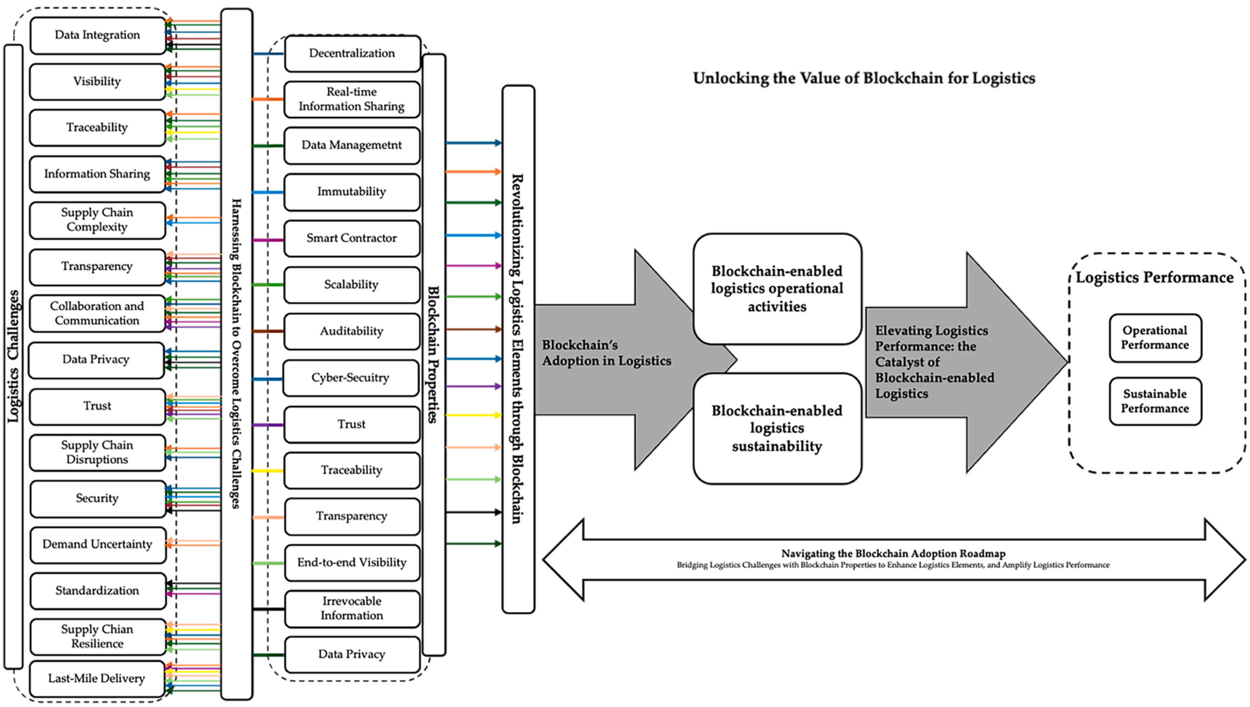

Fig. 1. Mapping blockchain properties to logistics challenges and their impact on logistics performance.

to effectively accommodate blockchain integration (Holm & Godscheit, 2020; Ozturan, Atasu, & Soydan, 2019). In summary, top management support and technology readiness are crucial in influencing the intention to adopt blockchain. Therefore, we propose the following hypothesis:

H10. Viability positively impacts the intention to adopt blockchain.

Blockchain-enabled logistics agility

In a competitive environment, logistics departments strive to be flexible and responsive to meet supply chain requirements. This concept is known as agility (Lai, Ngai, & Cheng, 2002). Logistics agility describes a firm's capability to rapidly adapt and modify strategies to address fluctuations in logistics operations and processes (Bai, Govindan, & Huo, 2023). This study specifically examines the moderating role of blockchain-enabled logistics agility in enhancing the relationship between TTF, STF, and the intention to adopt blockchain. Adopting blockchain aims to increase a firm's flexibility and responsiveness to manage the complexities and challenges of logistics. Blockchain improves a firm's ability to integrate new functionalities, quickly adapt sustainability strategies, and enhance decision-making processes (Beck, Birkel, Spieske, & Gebhardt, 2023). Blockchain supports a decentralized, immutable, and transparent network where all supply chain participants (i.e., suppliers, manufacturers, distributors, and customers) can interact in real time. This interaction promotes agility by enabling faster communication, coordination, decision-making (Aslam et al., 2023a), accelerating transactions, streamlining processes, and enhancing coordination, thereby strengthening the fit between logistics tasks and the technology. Furthermore, STF assesses the extent to which a technology contributes to the social, economic, and environmental dimensions of an organization's sustainability goals (Nozari & Nahr, 2022). The impact of blockchain-enabled logistics agility on the relationship among TTF, STF, and the intention to adopt blockchain is significant. Thus, we propose the following moderating hypotheses:

H11a. Blockchain-enabled agility moderates the relationship between TTF and the intention to adopt blockchain.

H11b. Blockchain-enabled agility moderates the relationship between STF and the intention to adopt blockchain.

Fig. 2 presents the conceptual model and illustrates the direction of the proposed hypotheses.

Methodology

Data collection

South Korea is renowned for its rapid adoption of emerging technologies. According to the World Economic Forum, it is globally recognized for its advanced implementation of AI and robotics (Smith, 2021). This provides an ideal scenario for analyzing organizational adoption behaviors of emerging technologies. In the realm of blockchain technology, South Korea leads in global development and application. In 2016, the national blockchain market was estimated at around \$20 billion, demonstrating early adoption across various sectors. By 2030, it is expected to grow to \$356.2 billion, propelled by broad acceptance of the technology. Our research seeks to gauge the perceptions of logistics managers from different sectors regarding blockchain adoption for logistics tasks. We gather data from Korean industries to empirically evaluate our hypotheses.

In this study, 600 logistics managers from high-tech industrial zones including Daejeon, Ulsan, Jeju, Namyangju, Gyeongsan, Suncheon, and Chuncheon participated in an online/offline survey. The sample encompassed representatives from nearly all major Korean industries, such as electronics, automotive, telecommunications, shipbuilding, chemicals, and steel. Invitations to join the survey were issued to 1020 logistics managers based on their experience with logistics tasks and knowledge of blockchain features, with the aim of discerning their intentions regarding blockchain adoption. Each manager represented a different firm, such that a total of 600 firms participated, representing a response rate of 56%. Twenty-four responses were deemed invalid due to incompleteness or bias, resulting in 576 valid responses that were used for further analysis and hypothesis testing.

Measures and questionnaire development

We carefully developed the questionnaire for this research, measuring constructs with scales validated in prior studies (see the questionnaire in Appendix A), and adapting the items to the context of the study. Initially prepared in English, the survey instruments were then translated into Korean by specialized translators. To ensure accuracy and equivalence in the translations, we employed the back-translation method with two independent translators. We engaged five qualified researchers (three from academia and two from industry) to review and analyze the understandability and consistency of the Korean version of the survey. These researchers also had expertise in blockchain applications for logistics and sustainability, aiding in the validation of the survey's measures and items.

Regarding measurement, this research utilizes twelve variable-based constructs including independent, dependent, and moderating variables, all measured on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The blockchain-enabled logistics tasks are differentiated across four dimensions: alignment, resilience, transparency, and integration. The measurement of alignment employs a four-item scale (Iranmanesh et al., 2023; Narasimhan & Kim, 2002), resilience is assessed with a three-item scale (Ambulkar, Blackhurst, & Grawe, 2015; Narasimhan & Das, 2001; Sheel & Nath, 2019), transparency is measured using a four-item scale (Liu, Zhou, Zhong, & Shi, 2023; Zhu, Song, Hazen, Lee, & Cegielski, 2018), and integration is measured by a four-item scale (Aslam et al., 2023a; Sheel & Nath, 2019). Additionally, the TTF of blockchain is measured using a three-item scale (Goodhue & Thompson, 1995).

The construct of social sustainability is measured with a four-item scale (Abdul-Rashid, Sakundarini, Raja Ghazilla, & Thurasamy, 2017), as are the economic dimension of sustainability (Adebanjo, Teh, & Ahmed, 2016), and the environmental dimension (Dey, Malesios, De, Chowdhury, & Abdelaziz, 2020). The three items measuring the STF originated from (Al-Emran & Griffy-Brown, 2023).

Blockchain-enabled logistics agility is posited as a moderating variable and measured by a four-item scale (Aslam et al., 2023a; Sheel & Nath, 2019). The viability construct was quantified using a six-item scale (Liang, Huang, H, & Li, 2021) that included factors such as top management support and technology readiness. The intention to adopt blockchain technology was measured with a three-item scale (Karahoca, Karahoca, & Aksöz, 2018; Maruping, Bala, Venkatesh, & Brown, 2017). The respondent profile for this study was constructed using four demographic queries: industry type, region, experience (in years), and qualifications.

Analysis and results

In this study, we employed partial least squares (PLS) to evaluate the reliability, convergence, and discriminant validity of our research model and empirically test it. The respondent profile is detailed in Table 4.

Common method bias

Survey-based research carries a high likelihood of bias, which we conscientiously sought to address through the design and development of the survey. We assured participants' anonymity and confidentiality in the cover letter that accompanied the questionnaires, also stating explicitly that there were no right or wrong answers. Our strategy to minimize 'straight-line' responses involved subdividing the survey question into several sections. We deployed two methods for formally assessing the presence of common method variance (CMV): the exploratory factor analysis (EFA) with unrotated factor analysis and the variance inflation factor (VIF). EFA aids in detecting CMV by examining if a single factor explains a majority of the variance, signaling potential bias in the measurement model. VIF assesses multicollinearity in regression models. Harman's one-factor EFA revealed that no singular factor

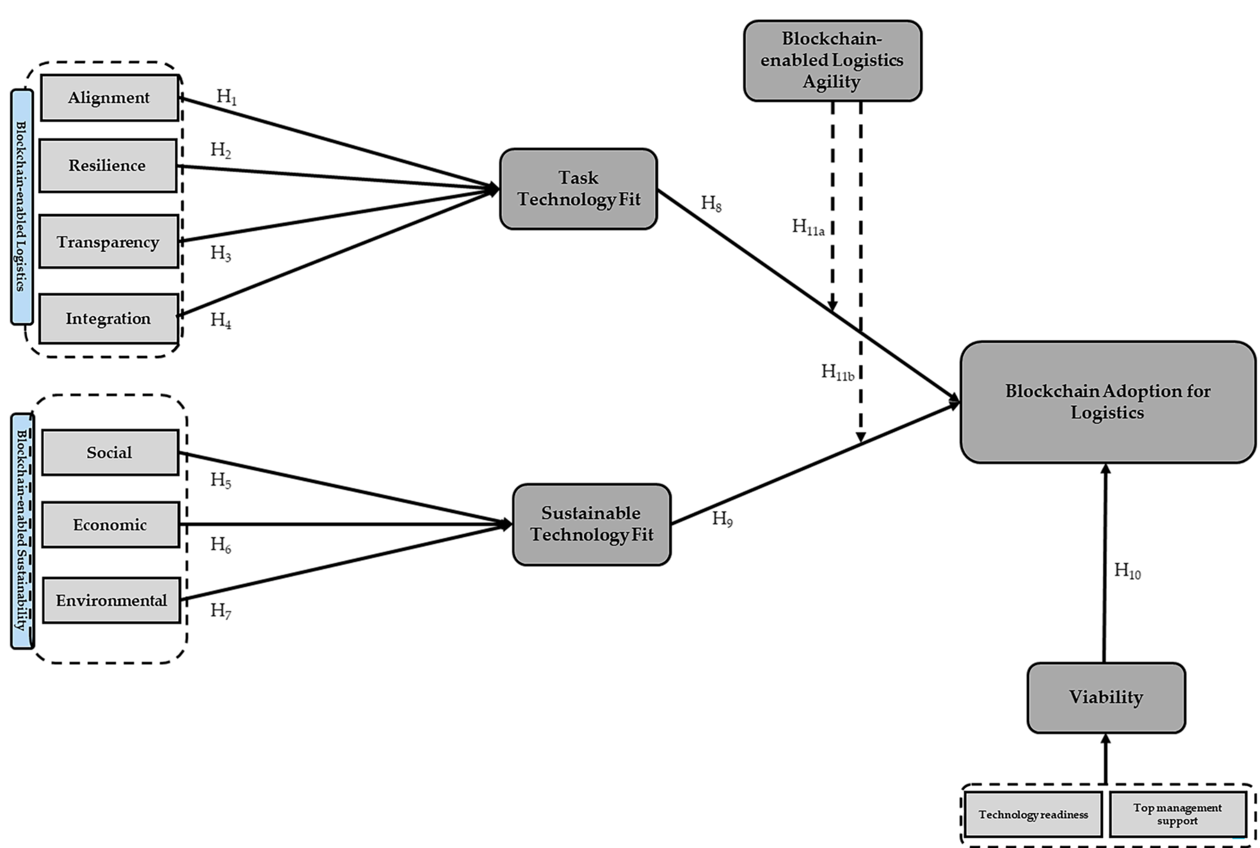

Fig. 2. Conceptual model of the study.

emerged in the unrotated structure (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). A VIF exceeding 3.3 suggests pathological collinearity and potential contamination by common method bias. Upon evaluating the VIF through PLS-SEM (see Table 5), we found the collinearity value to be under 2.5, thus indicating a low likelihood of common method bias affecting the study results.

Reliability and validity

As shown in Table 5, Cronbach's alpha values (α) ranging from 0.712 to 0.852 indicate robust reliability for each of the constructs. Additionally, all items' composite reliabilities (CR) range from 0.703 to 0.895, thereby exceeding the 0.70 threshold (Fornell & Larcker, 1981). The statistically significant factor loadings of all constructs, with coefficients greater than 0.710, further supports the constructs' reliability and validity. Moreover, the average variance extracted (AVE) values for all constructs surpass the 0.5 threshold and confirm strong convergent validity. Therefore, we affirm that the constructs' reliability and validity are both acceptable and sufficient.

Correlations and discriminant validity

To assess the discriminant validity of the constructs, we compared the square root of the AVE with the correlations among the constructs. Discriminant validity was further evaluated by examining the heterotrait-monotrait ratio (HTMT) of the correlations. The results indicate that all HTMT values fall below the recommended threshold of 0.85, thereby providing evidence of adequate discriminant validity. Furthermore, the square root of the AVE for each variable, as displayed on the diagonal, exceeded its corresponding correlations, offering additional support for discriminant validity (Henseler, Ringle, & Sarstedt, 2015; Kline, 2011). The results are summarized in Table 6.

Hypothesis testing

Direct effects

We tested the study's hypotheses using SMART-PLS4.0 software. The study examines the direct and moderating relationships between variables based on the conceptual model. Regarding the direct relationships proposed in hypotheses H_1, H_2, H_3, and H_4, we analyzed the impact of blockchain-enabled logistics tasks, namely alignment, resilience, transparency, and integration, on the TTF of blockchain. The results show that H_1 (b=0.032, $p > 0.05$) was not supported, indicating that alignment does not significantly influence the TTF. However, H_2, H_3, and H_4 were supported, with resilience (b=0.077, $p < 0.05$), transparency (b=0.783, $p < 0.05$), and integration (b=0.100, $p < 0.05$) significantly influencing the TTF. Secondly, the study examined the impact of blockchain-enabled social, economic, and environmental sustainability on the STF of blockchain. The proposed hypotheses were H_5, H_6, and H_7. The results indicate significant influences, with social (b=0.101, $p < 0.05$), economic (b=0.115, $p < 0.05$), and environmental (b=0.483, $p < 0.05$) aspects all impacting STF. Lastly, we studied the impact of blockchain's TTF, STF, and viability on the intention to adopt blockchain in logistics operations, to test hypotheses H_8, H_9, and H_{10} respectively. The results revealed significant influences of each on adoption intention: TTF (b=0.796, $p < 0.05$), STF (b=0.203, $p < 0.05$), and viability (b=0.636, $p < 0.05$). Table 7 presents the results for the direct relationships proposed in hypotheses H_1 to H_{10}.

Moderating effects

To examine the moderating effects, a PLS-SEM bootstrap re-sampling procedure with 5000 re-samples was implemented. The conceptual model suggests that blockchain-enabled logistics agility functions as a moderating variable among TTF, STF, and the intention to adopt

Table 4
Profile of Respondents.

Variable	Item	Sample	Percentage (%)
Industry Type	Electronics	150	26.0
	Automobiles	200	34.8
	Telecommunications	31	5.3
	Shipbuilding	45	7.8
	Chemicals	80	13.8
	Steel	70	12.1
Region	Daejeon	179	31.0
	Ulsan	140	24.3
	Jeju	50	8.7
	Namyangju	62	10.8
	Gyeongsan	50	8.7
	Suncheon	50	8.7
	Chuncheon	45	7.8
Experience (Years)	Below 1	0	0
	1–5 (under)	0	0
	5–10 (under)	89	15.4
	10–15 (under)	251	43.6
	15–20 (under)	201	34.9
	Above 20	35	6.1
Qualification	Diploma	20	3.5
	Undergraduate	109	19.0
	Master's	317	55.0
	PhD	80	13.9
	Certification	50	8.70

Table 5
Factor Loading, CR, AVE, and Alpha.

Variable	Items	Factor Loading	α	CR	AVE	VIF
Alignment (ALN)	ALN1	0.741	0.724	0.825	0.645	1.188
	ALN2	0.712				1.338
	ALN3	0.747				1.542
	ALN4	0.849				1.698
Resilience (RES)	RES1	0.710	0.712	0.817	0.601	1.316
	RES1	0.808				1.337
	RES2	0.868				1.392
Transparency (TRN)	TRN1	0.872	0.743	0.835	0.670	2.311
	TRN2	0.897				2.720
	TRN3	0.786				1.509
	TRN4	0.721				1.231
Integration (INT)	INT1	0.755	0.721	0.807	0.611	1.099
	INT2	0.711				1.237
	INT3	0.722				1.176
	INT4	0.735				1.128
Task Technology Fit (TTF)	TTF1	0.840	0.780	0.880	0.651	1.369
	TTF2	0.815				1.429
	TTF3	0.732				1.074
Social (SOC)	SOC1	0.832	0.762	0.703	0.690	1.357
	SOC2	0.715				1.401
	SOC3	0.721				1.205
	SOC4	0.705	0.788	0.881	0.641	1.032
Economic (ECO)	ECO1	0.731	0.798	0.895	0.698	1.141
	ECO2	0.835				1.027
	ECO3	0.748				1.137
	ECO4	0.722				1.200
Environmental (ENV)	ENV1	0.731	0.753	0.857	0.668	1.356
	ENV2	0.883				1.898
	ENV3	0.859				1.653
Sustainable Technology Fit (SFT)	STF1	0.771	0.741	0.852	0.657	1.222
	STF2	0.845				1.978
	STF3	0.819				1.927
Agility (AGL)	AGL1	0.718	0.771	0.753	0.632	1.297
	AGL2	0.754				1.309
	AGL3	0.763				1.358
	AGL4	0.745				1.397
Viability (VAB)	VAB1	0.712	0.850	0.880	0.653	1.390
	VAB2	0.821				2.407
	VAB3	0.841				2.297
	VAB4	0.745				2.410
	VAB5	0.757				2.340
	VAB6	0.730				2.388
Intention to Adopt Blockchain (BCA)	BCA1	0.717	0.717	0.794	0.663	1.188
	BCA2	0.711				1.251
	BCA3	0.818				1.237

Table 6
Correlations and Discriminant Validity.

	ALN	RES	TRN	INT	SOC	ECO	ENV	TTF	STF	VIB	AGL	BCA
ALN	0.803											
RES	0.473	0.775										
TRN	0.705	0.222	0.818									
INT	0.789	0.337	0.766	0.795								
SOC	0.114	0.287	0.111	0.126	0.830							
ECO	0.466	0.401	0.469	0.497	0.206	0.835						
ENV	0.666	0.438	0.656	0.589	0.134	0.762	0.817					
TTF	0.471	0.237	0.764	0.560	0.120	0.364	0.465	0.806				
STF	0.736	0.337	0.789	0.788	0.106	0.587	0.710	0.757	0.810			
VIB	0.755	0.454	0.803	0.752	0.689	0.473	0.711	0.636	0.804	0.808		
AGL	0.412	0.359	0.423	0.375	0.129	0.602	0.802	0.348	0.545	0.467	0.781	
BCA	0.508	0.249	0.595	0.820	0.329	0.312	0.344	0.405	0.396	0.665	0.467	0.794

n=576. Values in the diagonal represent each variable's square roots of the AVE.

Table 7
Direct relationships of proposed hypotheses.

Path		β	Mean	SD	t-value	p-value	R^2
H_1	Alignment → TTF	0.032	0.032	0.037	0.87	0.383	0.536
H_2	Resilience → TTF	0.712	0.680	0.042	12.45	0.014	
H_3	Transparency → TTF	0.783	0.783	0.048	16.41	0.000	
H_4	Integration → TTF	0.100	0.090	0.040	2.503	0.012	
H_5	Social sustainability → STF	0.101	0.101	0.049	2.065	0.039	0.326
H_6	Economic sustainability → STF	0.115	0.125	0.052	2.205	0.027	
H_7	Environmental sustainability → STF	0.483	0.475	0.052	9.331	0.000	
H_8	TTF → Intent to adopt blockchain	0.796	0.698	0.046	12.108	0.035	0.333
H_9	STF → Intent to adopt blockchain	0.203	0.200	0.057	3.562	0.000	
H_{10}	Viability → Intent to adopt blockchain	0.636	0.637	0.054	11.780	0.000	

Table 8
Moderating effects.

Path		β	Mean	SD	t -value	p-value
H_{11a}	(TTF x logistics agility) → Intention to adopt blockchain	0.295	0.100	0.046	4.076	0.038
H_{11b}	(STF x logistics agility) → Intention to adopt blockchain	0.136	0.136	0.044	3.075	0.002

Table 9
Summary of the hypothesis results.

Hypotheses and path		Relationship	Results
H_1	Alignment → TTF	Direct	Not Supported
H_2	Resilience → TTF		Supported
H_3	Transparency → TTF		Supported
H_4	Integration → TTF		Supported
H_5	Social sustainability → STF		Supported
H_6	Economic sustainability → STF		Supported
H_7	Environmental sustainability → STF		Supported
H_8	TTF → Intention to adopt blockchain		Supported
H_9	STF → Intention to adopt blockchain		Supported
H_{10}	Viability → Intention to adopt blockchain		Supported
H_{11a}	(TTF x logistics agility) → Intention to adopt blockchain	Moderator	Supported
H_{11b}	(STF x logistics agility) → Intention to adopt blockchain		Supported

blockchain, leading to the proposition of hypotheses H_{11a} and H_{11b}. Table 8 demonstrates that blockchain-enabled logistics agility interacts positively and significantly with the association between TTF and the intention to adopt blockchain (b=0.295, $p < 0.05$), supporting H_{11a}. Additionally, it interacts positively and significantly with the association between STF and the intention to adopt blockchain (b=0.136, $p < 0.05$), confirming H_{11b}. Table 9 presents the results of all hypotheses, and Fig. 3 displays the PLS-SEM diagram with beta and p-values.

Discussion

This study's findings are divided into two parts. The first part confirms that blockchain technology is exceptionally well-suited to address logistics management challenges due to its unique properties (Table 2) and presents a framework (Fig. 1) that highlights the value of blockchain adoption in logistics activities. This framework provides policymakers and decision-makers with a detailed understanding of potential logistics management challenges and the benefits from blockchain adoption. In the second part, the study categorizes the challenges faced by logistics into operational and sustainability domains. The conceptual model (Fig. 2) details these domains along with attributes of FVM, TTF, and STF pertinent to blockchain. TTF pertains to logistics tasks involved in operational activities such as alignment, resilience, transparency, and integration.

Conversely, STF addresses sustainability factors that include social, economic, and environmental dimensions. The study emphasizes the importance of management support and technology readiness (viability variable) for adopting blockchain technology. It also highlights the moderating role of blockchain-enabled agility between TTF, STF, and blockchain adoption, whereby the enhanced adaptability and responsiveness of blockchain-enabled logistics to meet sustainability and operational challenges increases managers' willingness to adopt the technology.

We employed PLS to evaluate the hypotheses of this study. The results demonstrate that blockchain's contribution to three logistics tasks—resilience, transparency, and integration—have a positive and significant impact on the TTF. These findings suggest that logistics managers consider blockchain technology valuable for enhancing the resilience, transparency, and integration of logistics functions. For instance, blockchains, characterized by decentralization, immutability,

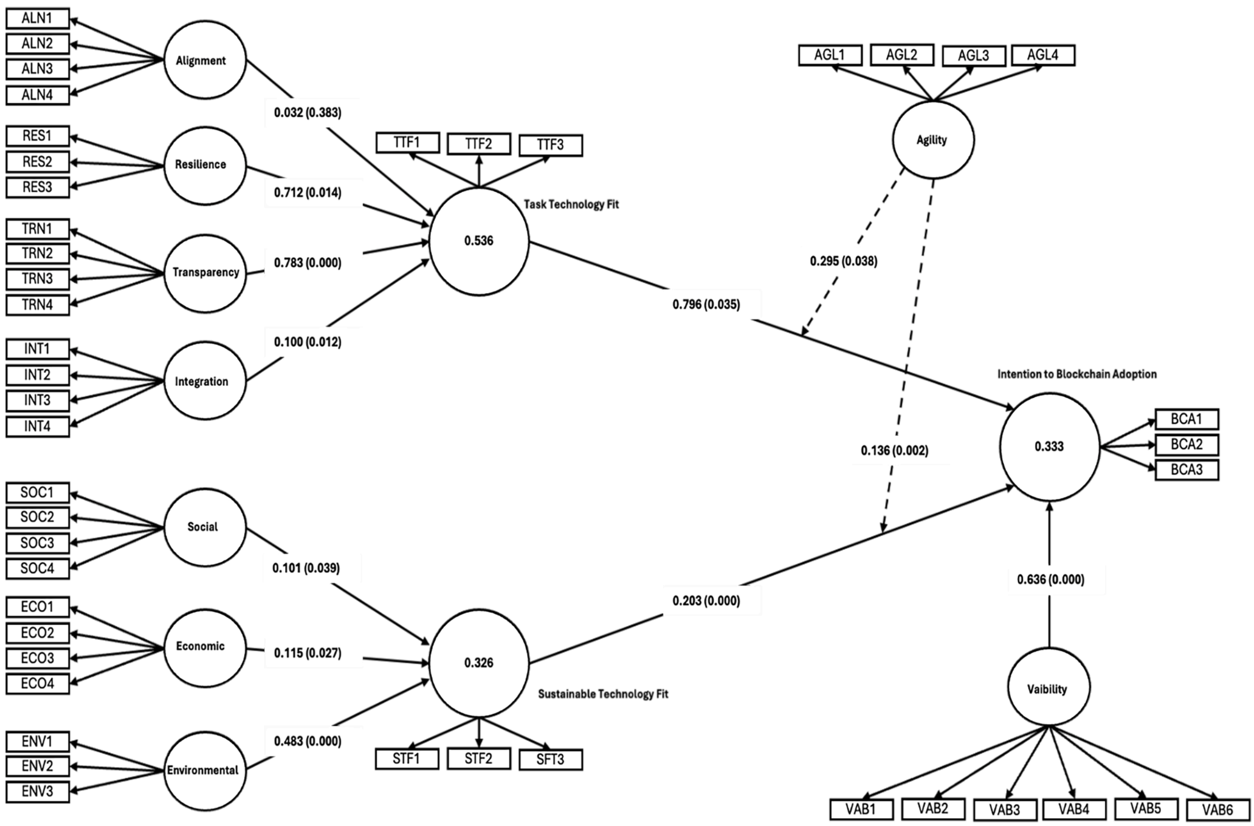

Fig. 3. Smart-PLS-SEM model with results.

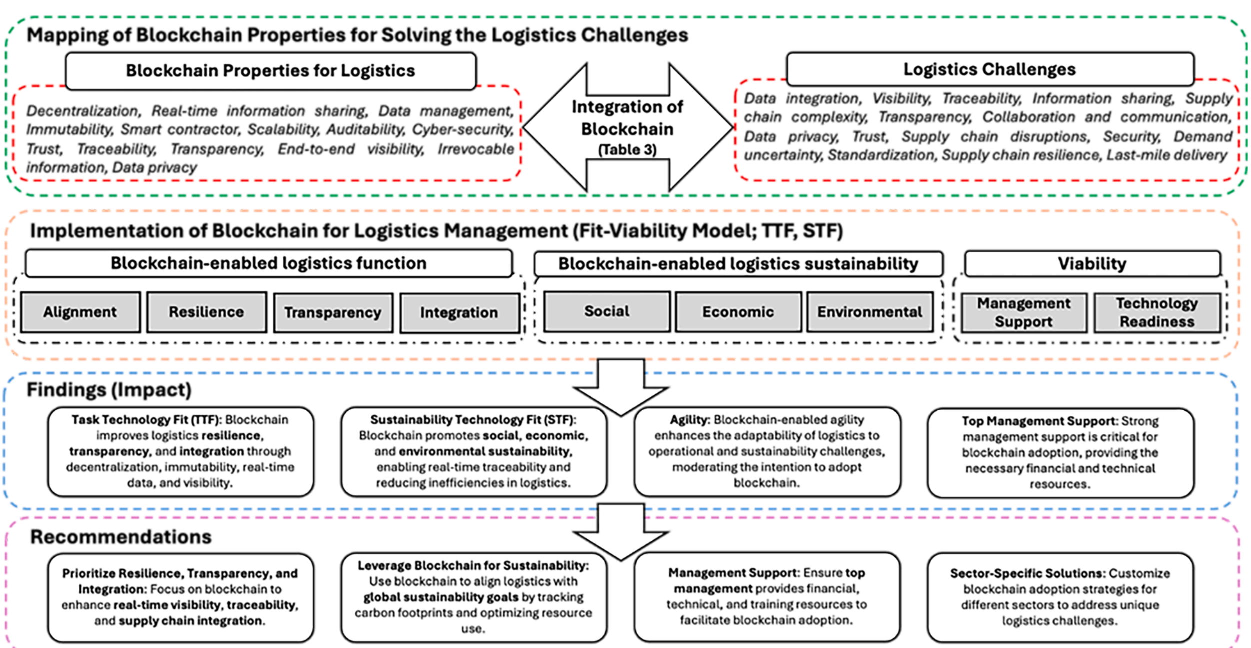

Fig. 4. Study findings, impact, and recommendations.

visibility, real-time data, and transparency, enhance logistics resilience by reducing the risk of system failures (Nagariya, Mukherjee, Baral, & Chittipaka, 2023; SadeghZadeh, Ansaripoor, & Oloruntoba, 2023). For enhancing logistics transparency, blockchain's characteristics ensure real-time visibility and traceability of goods, transactions, and processes. Moreover, blockchain technology facilitates internal and external integration by providing accurate, real-time information. Consequently, companies such as Walmart, Nestle, and Unilever have successfully implemented blockchain-based platforms to advance resilience, transparency, and integration in their food product logistics and supply chain functions (Yiannas, 2018). These components are crucial in determining the TTF of blockchain.

Conversely, blockchain's contribution to logistics alignment is deemed to have an insignificant impact on TTF. This finding implies that logistics managers view blockchain technology as not universally applicable across all industries (Dubey, Gunasekaran, & Foropon, 2022). This study featured participation of logistics managers from various sectors (i.e., electronics, automobile, telecommunication, shipbuilding, chemicals, and steel), suggesting varied perceptions about blockchain alignment. We also explored the impact of blockchain-enabled sustainability factors—social, economic, and environmental—on the STF of blockchain (Tian et al., 2021; Treiblmaier, 2019). The findings indicate that sustainability factors significantly and positively affect the STF of blockchain, affirming the belief of logistics managers in blockchain as a functional digital infrastructure promoting sustainable logistics management.

The study assessed the impact of TTF, STF, and viability on the intention to adopt blockchain for logistics functions. The results showed that TTF, STF, and viability significantly influence this intention. They further indicate that logistics managers perceive blockchain as a task technology for accomplishing logistics operations and a sustainable technology for enhancing the sustainability of logistics processes (Alazab, Alhyari, Awajan, & Abdallah, 2021; Wong, Yeung, Lau, & Kawasaki, 2023). From a viability standpoint, managers believe that top management is willing to implement blockchain and will provide essential support and resources for its deployment. These viability-related factors markedly influence the intention to adopt blockchain. Blockchain-enabled agility moderates the relationship between TTF, STF, and the intent to adopt blockchain. In summary, Fig. 4 outlines the study's findings, impacts, and recommendations.

Theoretical implications

The study enriches the literature in various ways. It highlights potential challenges in logistics management and establishes a connection between blockchain attributes and logistics issues (Table 3), previously unexplored in other studies. Additionally, it proposes a framework aimed at generating value from blockchain attributes to address specific logistics challenges.

This study utilizes existing theories, specifically the FVM and TTF, to examine the intention to adopt blockchain technology in logistics. It explores how logistics functions such as alignment, resilience, transparency, and integration relate to the TTF model, which has not been thoroughly investigated before. Additionally, this study evaluates the implications of blockchain technology across the social, economic, and environmental dimensions of sustainability. Moreover, it assesses the viability of blockchain adoption by examining factors like top management support and technological readiness. To our knowledge, this is the first study to examine the adoption of blockchain in logistics in light of its perceived contribution to operational functions and sustainability. By investigating the factors affecting the intention to adopt blockchain technology, this research illuminates the decision-making process around integrating emerging technologies into logistics management.

Managerial implications

The findings of this study provide valuable insights for managers, policymakers, and decision-makers on the application of blockchain technology in logistics management, offering a detailed understanding of blockchain's potential and requirements through a series of interconnected steps.

First, the research identifies practical challenges in logistics management (Table 2), allowing managers to pinpoint which areas might benefit from implementing blockchain technology. Second, the study links the properties of blockchain with potential solutions to these logistics management challenges (Table 3), guiding managers in utilizing blockchain to address specific issues. Third, the research demonstrates how blockchain enhances logistics alignment, resilience, transparency, integration, and sustainability, providing managers with insights to devise strategies that utilize blockchain to improve operations and sustainability. Fourth, the study examines TTF and STF in the context of blockchain adoption, helping managers determine if blockchain is suitable for their operational tasks and sustainability goals. If the fit is unsatisfactory, managers might consider other options or modify operations to better integrate blockchain. Finally, the study evaluates the practicality of blockchain adoption within a company's operations, assisting managers in deciding whether to implement the technology based on practicality and cost-effectiveness. If feasibility is low, alternative solutions may be considered, or ways to enhance feasibility may be sought. Ultimately, this comprehensive overview serves as a guide for decision-makers by providing a clear roadmap for considering the implementation of blockchain technology, urging managers to scrutinize the specific challenges they face, the potential benefits of blockchain, its alignment with their operations, and the feasibility of its implementation.

Conclusion, limitations, and future research

This study elucidates the role of blockchain technology in enhancing key logistics management functions such as resilience, transparency, integration, and sustainability by developing a conceptual model grounded in the FVM, TTF, and STF frameworks. Moreover, the research identifies specific logistics challenges and matches blockchain properties with effective solutions for these issues. By charting these connections, the study offers managers a comprehensive understanding of how blockchain can elevate operational efficiency and promote sustainable practices in their logistics operations. This guidance empowers decision-makers to strategically implement blockchain technology to meet both operational and sustainability goals, ultimately leading to stronger and more sustainable logistics systems.

Despite the promising theoretical and managerial implications, this study has some limitations. Firstly, the research is limited to analyzing blockchain adoption for logistics management, omitting other critical SCM functions. Therefore, future studies should investigate blockchain's applicability across various SCM functions, including sourcing and procurement, resource management, demand forecasting, last-mile logistics, and transportation. Secondly, while this study focuses on factors that facilitate blockchain implementation, it does not explore the challenges and barriers to adoption, which future research should address. Thirdly, although blockchain adoption is capital-intensive, this study does not provide a cost analysis; future research should offer a detailed examination of technology costs and benefits. This study is also limited to examining the adoption of blockchain for logistics management and does not consider the adoption of other emerging technologies such as AI, IoT, cloud computing, and robotics, which could be explored in future studies. Finally, the sample of this study was drawn from a specific population, and future studies need to replicate the findings in different geographical regions.

CRediT authorship contribution statement

Javed Aslam: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization, Funding acquisition. **Kee-hung Lai:** Writing – review & editing, Validation, Supervision, Funding acquisition. **Yun Bae Kim:** Writing – review & editing, Supervision, Data curation. **Horst Treiblmaier:** Writing – review & editing, Supervision, Methodology.

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Appendix A

Survey questionnaire

Measured with a 5-point Likert scale (1= Strongly disagree, 2= Disagree, 3= Neutral, 4= Agree, 5= Strongly agree)

Variable	Items	Source
Alignment	Blockchain can improve our firm's logistics capabilities. Blockchain can improve logistics coordination within our firm's internal departments. Blockchain can strengthen the relationship with our firm's suppliers. Blockchain can enhance logistics coordination for our firm's customers.	(Iranmanesh et al., 2023; Narasimhan & Kim, 2002)
Resilience	Blockchain enables our firm to rapidly adapt to market changes. Blockchain facilitates our firm's prompt adaptation to supply chain disruptions. Blockchain can enhance our firm's continuous high situational awareness.	(Ambulkar et al., 2015; Narasimhan & Das, 2001; Sheel & Nath, 2019)
Transparency	Blockchain can effectively manage and distribute logistics plans within our firm. Blockchain supports real-time information sharing about our firm's logistics processes. Blockchain facilitates the sharing of strategic information among our firm's stakeholders. Blockchain enables the secure dissemination of planning and implementation details across supply chain partners within the firm.	(Liu et al., 2023; Zhu et al., 2018)
Integration	Blockchain will enhance integration across logistics functions. Blockchain will improve logistics integration across departments. Integration with suppliers and stakeholders will be enhanced via blockchain. Logistics integration with customers will be enhanced through the use of blockchain.	(Aslam et al., 2023a; Sheel & Nath, 2019)
Task Technology Fit (TTF)	In my opinion, the functionality of blockchain aligns well with logistics tasks. Blockchain functions are adequate for logistics tasks. Blockchain functions fulfill the requirements for logistics tasks.	(Al-Maatouk et al., 2020; Goodhue & Thompson, 1995)
Social Sustainability	Blockchain technology can enhance workforce training and development. Blockchain can enhance relationships between internal and external departments. Blockchain can improve the workplace environment. Blockchain enhances job satisfaction.	(Abdul-Rashid et al., 2017)
Economic Sustainability	By utilizing blockchain, firms can reduce operational costs in logistics. By using blockchain, firms can enhance customer and supplier satisfaction. With blockchain, firms can enhance delivery performance. Using blockchain, firms can improve their overall financial performance.	(Adebanjo et al., 2016)
Environmental Sustainability	Blockchain aids in reducing waste across logistics processes. Blockchain enables firms to achieve resource efficiency in logistics processes. Blockchain assists firms in enhancing compliance with environmental standards.	(Dey et al., 2020)
Sustainable Technology Fit	In my opinion, blockchain can enhance sustainable practices in logistics. In my opinion, blockchain functions are sufficiently related to logistics sustainability. In my opinion, blockchain functions are well-suited for logistics sustainability tasks.	(Al-Emran & Griffy-Brown, 2023)
Agility	Blockchain facilitates a swift and effective response to logistics challenges. Blockchain can manage interruptions in logistics. Blockchain can enhance logistics forecasting. Blockchain can improve logistics functions.	(Aslam et al., 2023a)
Viability	Top management is considering the adoption of blockchain technology. Top management possesses sufficient financial resources for blockchain adoption. Top management recognizes the advantages of blockchain adoption. Blockchain development aligns with our firm's strategic roadmap. Our firm is well-prepared with measures to integrate blockchain technology. The introduction and potential of blockchain are advantageous for our firm.	(Liang, Huang, H, & Li, 2021)
Blockchain Adoption	In the near future, our firm will implement blockchain in logistics operations. I anticipate that our firm will increasingly utilize blockchain technology in the future. I believe our firm's employees are comfortable with adopting blockchain technology.	(Karahoca et al., 2018; Maruping et al., 2017)

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