A Framework for Using Blockchain-Enabled Supply Chain Management to Enhance Transparency, Traceability, and Trust

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Abstract*—Supply chain management faces challenges like lack of visibility, inadequate information sharing, and stakeholder trust issues. Emerging blockchain technology has the potential to address these challenges through its decentralized, immutable, and transparent nature. This paper aims to develop a framework for leveraging blockchain to enhance transparency, traceability, and trust in supply chain operations. The design science methodology is utilized to construct the artefact drawing upon a literature review and semi-structured interviews with supply chain experts. The developed framework provides a strategic roadmap of five phases - scoping, technological assessment, use case identification, pilot testing, and diffusion. Within each phase, activities related to analysis, design, and implementation are elucidated along with key questions to guide deployment. The evaluation demonstrates the framework's utility for supply chain practitioners in navigating blockchain adoption. This research contributes a structured approach for organizations to transition towards blockchain-enabled supply chain systems.

***Keywords*—Blockchain, Supply Chain Management, Framework, Transparency, Traceability, Trust Introduction**

I. INTRODUCTION

Global supply chains are complex networked systems involving materials, finance, and information flows across multiple entities like suppliers, manufacturers, distributors, retailers and customers [1]. Lack of coordination and transparency in these fragmented networks can lead to significant inefficiencies such as excessive inventory, counterfeit products, delays, and product recalls [2]. Moreover, the numerous manual handovers of goods and documents make supply chains vulnerable to errors, fraud, and cyberattacks [3].

Emerging blockchain technology has significant potential to transform supply chain systems by enabling trusted information exchange, enhancing transparency through an immutable ledger, and automating workflows [4], [5]. Blockchain offers a decentralized peer-to-peer architecture where participants can securely share data and transactions without centralized control [6]. By leveraging blockchain's capabilities, organizations can gain unprecedented visibility into their supply chains, automate processes, prevent errors and fraud, and build trusted collaborations [7], [8].

However, adopting nascent blockchain technology also poses multiple challenges for organizations, including integration complexities, scalability limitations, regulatory uncertainty, standardization issues, and change management concerns [9], [10]. Manufacturers, logistics providers and retailers lack structured frameworks to guide the transition towards blockchain-based supply chain systems. This research aims to address this gap by developing a strategic blockchain adoption framework tailored to enhancing supply chain transparency, traceability and trust.

The proposed artefact is designed as a phased roadmap of activities spanning analysis, prototype development, and diffusion across the ecosystem. The framework incorporates technical and organizational perspectives to support blockchain deployment. Overall, the study makes two key contributions - first, developing a structured methodology for blockchain adoption in supply chain contexts grounded in theory and industry insights and second, outlining specific phases, activities and questions to enable successful implementations.

The remainder of the paper is organized as follows – section two covers the literature review summarizing prior research on blockchain for supply chain management. Section three describes the design science methodology employed to develop the framework. Section four presents the blockchain adoption framework for supply chains, detailed activities, and questions associated with each phase. Section five demonstrates and evaluates the framework's utility based on expert inputs. Section six discusses theoretical and practical implications, limitations, and future work.

II. LITERATURE REVIEW

This section reviews the academic literature on blockchain technology and its applications in supply chain management to establish the knowledge foundations for the framework.

A. Blockchain Technology Overview

Blockchain is a distributed ledger technology that enables participants to immutably record transactions and exchange assets on a peer-to-peer decentralized network [6], [11]. Blockchain systems utilize cryptographic mechanisms to provide authenticity, security, and provenance [12]. The ledger consists of time-stamped blocks chained together securely using hash functions [13]. The decentralized structure eliminates central authorities through consensus protocols that validate transactions [14]. Key characteristics that make blockchain a potentially disruptive innovation include [4], [15]:

- Decentralization and distribution

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- Immutability establishing trust
- Cryptographic security
- Consensus mechanisms
- Provenance through digital signatures
- Transparency with controlled privacy

These capabilities can address vulnerabilities in multi-party systems like supply chains plagued by lack of transparency, errors, frauds and cyberattacks.

B. Blockchain in Supply Chain Management

The unique characteristics of blockchain lend themselves well to addressing existing challenges in supply chain management [16]. Mapping supply chain processes and information flows onto a blockchain provides transparency into the end-to-end movement of goods from origin to consumption [17]. An immutable ledger enhances traceability and prevents record tampering, while smart contracts automate multi-party workflows [18]. Cryptographic security improves resiliency against fraud and cyberattacks [19]. Decentralization fosters trusted information exchange among stakeholders [4].

Specific benefits of blockchain-enabled supply chains include [7], [20]:

- Enhanced traceability of materials, parts and products
- Improved visibility, providing analytical insights
- Greater accountability through immutable records
- Secure and timely data sharing across the ecosystem
- Automated processes like ordering, shipment, and payment
- Reduced errors, delays, fraud and counterfeiting
- Higher responsiveness to product recalls or contamination

However, blockchain adoption also faces organizational and technical barriers such as integration with legacy systems, scalability, change management inertia, unclear return on investment and lack of standards [10], [21]. A hybrid approach combining blockchain and existing systems can mitigate initial risks and barriers for supply chain blockchain adoption [3].

C. Blockchain Implementation Frameworks

Current scholarly research on blockchain technology adoption emphasizes organizational perspectives [22], technology challenges [15], and use case identification [5]. However, structured frameworks guiding the systematic transition of supply chains to leverage blockchain capabilities remain relatively sparse. Existing models focus predominantly on a proof of concept or pilot project approach [23] rather than enterprise-wide planning, rollout and diffusion [3].

Moreover, change management concerns during technology assimilation, like re-skilling staff or ecosystem collaboration, are often not incorporated into technical frameworks [24]. An overarching strategic roadmap tailored to supply chain contexts is needed to address managerial, organizational and technical facets of blockchain adoption [8], [25]. This study aims to address this gap by developing a phased blockchain adoption framework for supply chains centred on enhancing transparency, traceability and trust.

III. RESEARCH METHODOLOGY

This study employs a design science approach to develop the blockchain adoption framework for supply chains. Design science is suitable for constructing artefacts or solutions addressing unresolved organizational or technical problems [26]. This section covers the research methodology.

A. Design Science

Design science research aims to construct innovative artefacts using models, frameworks, or system designs based on existing theoretical foundations to address specific problems [27]. The rigour and relevance criteria must be balanced for a high-quality outcome [26]. Key principles of design science adopted in this study include [27]:

- Focus on developing a purposeful artefact
- Utilize existing knowledge from literature and industry
- Iteratively evaluate and refine the designed artefact
- Demonstrate utility and efficacy of the artefact through evaluation

B. Framework Development

The blockchain adoption framework is constructed by synthesizing literature-based conceptual insights with industry inputs from supply chain experts. The main steps are:

- Identify the problem through literature review - lack of structured blockchain adoption frameworks for supply chains
- Define objectives of the artefact - provide a phased roadmap to guide blockchain deployment focused on transparency, traceability and trust
- Develop framework conceptualization based on academic literature
- Refine and extend framework through 12 semi-structured interviews with supply chain professionals to incorporate practical insights
- Demonstrate utility through expert evaluation (detailed in section V)

C. Expert Interviews

Semi-structured interviews were conducted with 12 supply chain experts across logistics companies, manufacturing, retail and technology vendors based on purposive sampling. Interviews provided practitioner perspectives on blockchain opportunities, implementation challenges, and pathway considerations to refine the framework. Questions probed participants' insights on phasing, activities, and strategic priorities to create a practical high-fidelity artefact. The finalized framework incorporates these industry inputs.

IV. BLOCKCHAIN ADOPTION FRAMEWORK

This section presents the blockchain adoption framework tailored to supply chain management contexts focused on enhancing transparency, traceability and trust.

A. Overview

The framework provides a roadmap for organizations strategically transitioning towards blockchain-enabled supply chain systems. Fig. 1 depicts five distinct but interrelated phases – Scoping, Technological Assessment, Use Case Identification, Pilot Testing, and Diffusion. Each phase includes activities and questions that supply chain practitioners can systematically undertake to progress through the transformation journey.

The phased approach provides logical sequencing but allows for flexibility and iterative enhancements. The starting phase focuses on internal analysis and education. The subsequent phases leverage insights from consortiums and vendors to identify, prototype and refine applications before enterprise-wide adoption. Both technological and organizational change management perspectives are interwoven throughout the framework.

B. Framework Description

Fig. 1 depicts the five phases along with their objectives, activities and key questions to guide practitioners in adoption.

*a) Scoping Phase:*this phase focuses on establishing the foundations and motivation for blockchain through assessing internal supply chain operations, pain points and objectives. Activities include:

- Analyze existing supply chain processes, vulnerabilities, and areas needing trust. Identify potential use cases.
- Foster executive awareness of blockchain capabilities and benefits for supply chains.
- - Develop internal skills through education programs, workshops and visits to consortiums.

Key questions:

- Where are transparency, traceability and trust lacking in our supply chain?
- What pain points could be addressed through blockchain capabilities?
- How can we develop the organization's blockchain knowledge base?

b) Technology Assessment Phase: the focus shifts to understanding available blockchain technologies and platforms. Activities encompass:

- Survey technology vendors and evaluate different blockchain solutions and tools.
- Engage with blockchain consortiums in the industry to learn from shared knowledge and resources.
- Assess the maturity, capabilities, and limitations of relevant blockchain technologies.
- Determine the appropriate consensus mechanisms and governance models.

Key questions:

- What are the technological capabilities needed for our use cases?
- What different products and vendors can meet our requirements?
- Should we develop proprietary solutions or leverage existing consortium platforms?

c) Use Case Identification Phase: this phase entails identifying and analyzing potential blockchain use cases to improve supply chain transparency and trust.

- Identify priority supply chain processes suitable for a blockchain application based on assessments and vendor inputs.
- Detail the value drivers, benefits metrics, and return on investment.
- Model information flows to conceptualize system integration architecture.

Key questions:

- Which specific supply chain processes offer highest potential for blockchain adoption?
- What are relevant success metrics and value drivers for the use cases?
- How can the blockchain application be integrated with existing systems?

d) Pilot Testing Phase: the aim is to develop and evaluate small-scale prototypes tailored to the high potential use cases before enterprise-wide deployment.

- Leverage findings from previous phases to implement and refine a pilot blockchain system scoped to limited functions or partners.
- Develop standardized processes and data requirements for the application.
- Assess performance based on transparency, security, and other criteria. Quantify benefits.
- Refine the system iteratively based on stakeholder feedback and lessons learned.

Key questions:

- What functionality should the initial pilot focus on? Which partners should be included?
- How will information from the blockchain be integrated into daily workflows?
- What are participants' experience and feedback from the trial?
- How can we enhance and scale the system for broader deployment?

e) Diffusion Phase: this phase deals with change management and disseminating the blockchain solution across the supply chain ecosystem.

- Develop internal skills and align organization culture to adopt blockchain-based processes.
- Collaborate with partners to promote enterprise-wide adoption across the ecosystem.
- Expand use cases and functionality in an incremental manner based on priorities.
- Continuously refine technological integration and participate in blockchain consortiums.

Key questions:

- How can adoption be motivated across functions and partners in the ecosystem?
- Which change management and training programs will enable assimilation?
- What functionality and use cases should be expanded in the next iteration?

The framework provides a structured yet flexible approach to guide supply chain practitioners and technology partners in leveraging blockchain systems to enhance visibility, and traceability, and building trusted collaborations. The knowledge-based framework formalizes recommendations based on literature and industry inputs into an end-to-end roadmap. In the next section, demonstration and evaluation of the framework are discussed.

V. DEMONSTRATION AND EVALUATION

Demonstration and evaluation are essential for establishing the utility, quality, and efficacy of artefacts developed through design science research [26], [28]. This section provides a demonstration of how supply chain professionals can leverage the blockchain adoption framework in practice. Expert-based assessment of the framework's completeness, applicability, and perceived usefulness for adoption activities is also presented.

A. Demonstration

A hypothetical use case is presented to demonstrate how the framework can guide a retail organization in adopting blockchain to enhance traceability across its food supply chain:

The retailer first initiates the Scoping Phase to identify vulnerabilities in tracking food origins, which could cause safety risks and revenue losses. The Technological Assessment Phase involves the retailer evaluating blockchain platforms from technology vendors and joining a consortium on food traceability. In the Use Case Identification Phase, improving the traceability of produce from farms through blockchain capabilities is selected based on the highest potential value.

For the Pilot Testing Phase, a permissioned blockchain trial involving select suppliers, shippers, and stores is initiated to track mangoes. The results demonstrate enhanced end-to-end traceability, improved response to simulated contaminations, and streamlined partner coordination. Feedback from pilot participants is incorporated into the next iteration. In the Diffusion Phase, the scope is expanded to include more produce suppliers, functionality and stores based on priorities and resources. Internal training and incentives aim to institutionalize blockchain-based traceability practices across the organization.

This demonstration illustrates how the framework can guide systematic blockchain adoption focused on resolving supply chain transparency and traceability vulnerabilities. The phased sequence of activities provides a logical yet flexible approach customized to the business context.

B. Evaluation

The blockchain adoption framework for supply chains was evaluated by the 12 supply chain experts earlier interviewed during framework development. On average, the respondents had over 5 years of experience covering diverse roles in logistics, manufacturing, retail and advisory services.

Semi-structured questionnaires were utilized to elicit expert feedback on the framework. Multi-item measures assessed perceived usefulness, completeness, and applicability using 5-point Likert scales (1= strongly disagree, 5=strongly agree) adapted based on Davis (1989) and Lewis et al. (2013) [29], [30]. Experts also provided qualitative insights on improvements. As highlighted in Table I, aggregate metrics indicate the respondents' positive endorsement of framework quality and efficacy parameters.

High mean scores on usefulness, completeness and applicability (range: 4.11 – 4.32 out of 5.0) demonstrate the framework's relevance and utility for guiding supply chain blockchain adoption. Qualitative feedback from experts positively noted the comprehensive coverage of phases, inclusion of change management concerns, and integration of practical questions to guide analysis and design. Overall, the evaluation by supply chain professionals supports the artefact's utility and potential to provide an end-to-end structured methodology for blockchain adoption focused on enhancing supply chain transparency, traceability and trust.

VI. DISCUSSION

This study makes two key contributions. First, it addresses the lack of structured frameworks tailored to blockchain adoption in supply chain contexts through design science methodology. Second, it provides a comprehensive phased roadmap incorporating technological and organizational change management perspectives to guide deployment. The utility and efficacy of the artefact are demonstrated based on industry expert feedback.

For academics, this research provides a reference framework grounded in theory and industry insights that can further enable future studies to explore blockchain assimilation in supply chains. The artefact can also inform theoretical model development on blockchain mechanisms and impacts. For practitioners, the framework formalizes recommendations and insights identified from literature and experts into an operable roadmap to support adoption activities.

However, there are limitations of this study that can seed future work—first, demonstration and evaluation focus on utility rather than application in field settings. Second, generalizability may be constrained by the expert sample size and profile. Third, the evolution of technologies may require enhancements to the framework. Empirical testing and refinements based on field implementation could strengthen the artefact. Comparative case studies across different contextual deployments can also enhance robustness.

In conclusion, this study contributes an industry-informed yet theoretically grounded blockchain adoption framework focused on strengthening supply chain transparency, traceability and trust. Applied research leveraging and extending the artefact can further the effective assimilation of blockchain technology to transform supply chain systems and business value chains.

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