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Blockchain Adoption Readiness in Supply Chain Networks: A Design Science-Based Assessment Model

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Blockchain Adoption Readiness in Supply Chain Networks: A Design Science-Based Assessment Model

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“O real não está na saída nem na chegada: ele se dispõe para a gente é no meio da travessia.”

Guimarães Rosa

ABSTRACT

KATHERINE KANEDA MORAES. **Blockchain adoption readiness in supply chain networks:** a design science-based assessment model. 2026. PhD thesis (PhD in Industrial Engineering). Post Graduate Program in Industrial Engineering, Federal University of São Carlos, São Carlos, 2026.

Blockchain technology has attracted significant interest in supply chain management due to its potential to enhance transparency, traceability, and interorganizational coordination. Despite its promise, blockchain adoption in supply chain networks remains limited, largely due to the complexity of decision-making and the multidimensional nature of adoption challenges. Existing research has predominantly focused on identifying isolated barriers or success factors, offering limited guidance on how organizations can systematically assess their readiness before committing to implementation. The objective of this PhD thesis is to advance the understanding and assessment of organizational readiness for blockchain adoption in supply chain networks and to translate this knowledge into a decision-oriented evaluation model. To address this problem, the thesis adopts an article-based research design composed of four cumulative studies. The first two studies investigate technological and non-technological barriers to blockchain adoption in supply chains and the strategies proposed to mitigate them, with particular attention to adoption stages and stakeholder characteristics. The third study addresses the methodological problem of how readiness models for emerging digital technologies in operations and supply chain management should be designed and structured, resulting in a Design Science Research-based reference architecture. The fourth study builds on the preceding findings to design, develop, and evaluate an organizational readiness assessment artifact for blockchain adoption, employing fuzzy logic to operationalize readiness conditions and provide an interpretable overall readiness classification. The results of the thesis contribute to the literature by consolidating and structuring readiness conditions for blockchain adoption from technological, organizational, environmental, and interorganizational perspectives, and by demonstrating how existing theories can be consciously adapted to this context. Methodologically, the thesis contributes a systematic approach for developing readiness models and a validated readiness assessment artifact. From a practical perspective, the proposed model helps organizations assess their readiness to adopt blockchain, identify critical areas for improvement, and avoid premature implementation decisions. Overall, the thesis bridges conceptual discussions of blockchain adoption with actionable readiness assessment for supply chain networks.

Keywords: Blockchain Technology; Readiness Model; Readiness assessment; Barriers; Supply Chain; Operations and Supply Chain Management; Design Science Research; Fuzzy Logic.

RESUMO

KATHERINE KANEDA MORAES. **Prontidão para a adoção de blockchain em cadeias de suprimentos**: um modelo de avaliação baseado em *Design Science* Research. 2026. Tese (Doutorado em Engenharia de Produção). Programa de Pós-Graduação em Engenharia de Produção, Universidade Federal de São Carlos, São Carlos, 2026.

A tecnologia *blockchain* tem atraído significativo interesse na gestão da cadeia de suprimentos devido ao seu potencial para ampliar a transparência, a rastreabilidade e a coordenação interorganizacional. No entanto, apesar de seu potencial, a adoção de *blockchain* em redes de cadeias de suprimentos ainda permanece limitada, em grande parte devido à complexidade do processo decisório e à natureza multidimensional dos desafios de adoção. As pesquisas existentes têm se concentrado predominantemente na identificação de barreiras ou fatores de sucesso de forma isolada, oferecendo orientação limitada sobre como as organizações podem avaliar sistematicamente sua prontidão antes de se comprometerem com a implementação. O objetivo central da pesquisa foi avançar na compreensão e na avaliação da prontidão organizacional para a adoção de blockchain em redes de cadeias de suprimentos, bem como traduzir esse conhecimento em um modelo de avaliação orientado à tomada de decisão. Para atingir esse objetivo o relatório de pesquisa foi estruturado em artigos, composto por quatro estudos cumulativos. Os dois primeiros estudos investigaram barreiras tecnológicas e não tecnológicas à adoção de blockchain em cadeias de suprimentos, bem como as estratégias propostas para mitigá-las, com atenção especial aos estágios de adoção e às características dos stakeholders. O terceiro estudo abordou o problema metodológico de como modelos de prontidão para tecnologias digitais emergentes em gestão de operações e da cadeia de suprimentos devem ser concebidos e estruturados, resultando em uma arquitetura de referência baseada em *Design Science Research*. O quarto estudo, fundamentado nos trabalhos anteriores projetou, desenvolveu e avaliou um artefato de avaliação da prontidão organizacional para a adoção de *blockchain*, empregando a lógica *fuzzy* para operacionalizar as condições de prontidão e fornecer uma classificação geral de prontidão interpretável. Os resultados da tese contribuem para a literatura ao consolidar e estruturar as condições de prontidão para a adoção de blockchain a partir de perspectivas tecnológicas, organizacionais, ambientais e interorganizacionais, bem como ao demonstrar como teorias existentes podem ser adaptadas a esse contexto. Do ponto de vista metodológico, a tese contribui com uma abordagem sistemática para o desenvolvimento de modelos de prontidão e com um artefato validado de avaliação da prontidão. Sob uma perspectiva prática, o modelo proposto apoia as organizações na avaliação de sua prontidão para adotar blockchain, na identificação de áreas críticas de melhoria e na prevenção de decisões prematuras de implementação. De modo geral, a tese aproxima as discussões conceituais sobre adoção de *blockchain* de uma avaliação acionável da prontidão em redes de cadeias de suprimentos.

Palavras-chave: Tecnologia *Blockchain*; Modelo de Prontidão; Avaliação da Prontidão; Barreiras; Cadeia de Suprimentos; Gestão de Operações e da Cadeia de Suprimentos; *Design Science Research*; Lógica *Fuzzy*.

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1 INTRODUCTION

This chapter introduces the thesis by presenting the research context, the motivation for investigating blockchain adoption readiness in supply chains, the research objectives, the study's justification, an overview of the research method, and the thesis's overall structure.

1.1 Contextualization and Motivation

Supply chains represent a critical empirical setting for investigating contemporary organizational challenges because they operate as interorganizational systems characterized by multiple, interdependent actors, distributed decision-making, heterogeneous information systems, and fragmented data flows across firms and tiers (Culot *et al.*, 2024; Huang; Ghadge; Yates, 2024; Swink *et al.*, 2024). These characteristics create persistent challenges related to information visibility, coordination, and the reliability of shared records, particularly when organizations must monitor flows of goods, trace product histories, and align decisions across organizational boundaries (Swink *et al.*, 2024). As supply chains become more extended and multi-tiered, limitations in upstream and downstream visibility further intensify coordination difficulties and increase dependence on accurate and trustworthy interorganizational information (Huang; Ghadge; Yates, 2024; Kalaiarasan *et al.*, 2022). Consequently, supply chains constitute an environment in which information-related problems are structural and recurrent rather than exceptional, making them a relevant context for examining mechanisms that may improve data sharing and coordination among participating organizations (Culot *et al.*, 2024; Swink *et al.*, 2024).

Blockchain has attracted growing attention in supply chains because its core characteristics appear particularly well aligned with some of the most persistent information, traceability, and coordination challenges of interorganizational supply networks (Risso *et al.*, 2023). Early work by Kshetri (2018) argued that blockchain could contribute to key Supply Chain Management objectives by enhancing transparency, accountability, auditability, and traceability, while also supporting improvements in cost, quality, speed, dependability, risk reduction, sustainability, and flexibility. More recent research has reinforced this view by showing that blockchain can support information sharing in distributed networks, create immutable and traceable digital records of historical transactions, and provide a more reliable basis for data exchange across fragmented and globally dispersed supply chains (Ahmed; MacCarthy, 2023).

This relevance becomes particularly evident in traceability-oriented applications, since organizations increasingly require reliable ways to verify provenance, monitor product and process histories, address counterfeiting and quality concerns, and respond more effectively to regulatory, sustainability, and customer demands (Ahmed; MacCarthy, 2023). In this sense, blockchain has attracted attention not merely because it is a novel digital technology, but because it is perceived as a potentially valuable mechanism for improving visibility, trustworthiness, and coordination across supply chain actors, particularly when combined with complementary technologies such as IoT-based sensing, digital identification, and broader data-capture infrastructures (Kshetri, 2018; Risso *et al.*, 2023).

Yet, despite these perceived advantages, blockchain adoption in supply chains remains far from straightforward. Although blockchain has been widely recognized as a technology with the potential to improve transparency, traceability, efficiency, and trust across supply networks, its diffusion in practice has been considerably slower than expected, with many initiatives remaining at the pilot or demonstration stage rather than reaching broad-scale implementation (Kouhizadeh; Saberi; Sarkis, 2021). This slow adoption reflects not a lack of interest in the technology but rather the presence of multiple, interrelated barriers that hinder implementation. Prior research shows that blockchain adoption in supply chains is constrained by technological immaturity, security and privacy concerns, regulatory uncertainty, limited organizational knowledge and expertise, hesitation to replace legacy systems, and unclear expectations regarding benefits and return on investment (Kouhizadeh; Saberi; Sarkis, 2021; Mathivathanan *et al.*, 2021).

In addition, interorganizational challenges such as a lack of information sharing, trust management issues, communication gaps among supply chain partners, uneven technological readiness, and high investment requirements further complicate adoption, especially in fragmented and multi-actor supply chain environments (Khan *et al.*, 2023; Mathivathanan *et al.*, 2021). Taken together, the literature suggests that the central issue is not whether blockchain offers value for supply chains, but whether organizations and their partners possess the conditions necessary for successful adoption.

To overcome the barriers that constrain blockchain adoption and increase the likelihood of successful implementation, organizations operating in supply chain contexts need to develop readiness before substantial adoption efforts are undertaken (Irannezhad *et al.*, 2021). From the perspective of Organizational Readiness for Change (ORC), higher levels of organizational readiness increase the likelihood of successful innovation implementation while reducing the risk of failure (Jöhnk; Weißert; Wyrtki, 2021; Snyder, 2001; Weiner, 2009). Readiness assessment may therefore be understood as a systematic analysis of an organization's ability to face and undertake a transformational process or change (Pirola; Cimini; Pinto, 2020), helping organizations determine whether they are prepared to initiate adoption and identify areas requiring further development (Aziz; Yusof, 2012; Saad; Bahadori; Jafarnejad, 2021).

Within this pre-adoption context, a readiness perspective is more appropriate than a maturity perspective. Readiness refers to the degree of preparation before implementation, whereas maturity concerns the level of advancement achieved after adoption has begun or after the innovation has evolved in use (Botha, 2018; Monshizadeh *et al.*, 2023; Pacchini *et al.*, 2019). Because blockchain remains at a pre-adoption or early-adoption stage in many organizational settings, assessing readiness is currently more relevant than evaluating maturity (Antony; Sony; McDermott, 2023; Felippes *et al.*, 2022). In this sense, readiness assessment can support organizational decision-making by helping firms identify their level of preparation, as well as potential barriers and enabling conditions, before substantial implementation efforts are undertaken (Lokuge *et al.*, 2019; Pirola; Cimini; Pinto, 2020).

Although readiness assessment has become an increasingly relevant pre-adoption concern, the literature still offers limited instruments for evaluating organizational readiness in emerging technology contexts. Prior studies identify recurring limitations in existing readiness and maturity approaches. Some models emphasize technological aspects while giving insufficient attention to non-technological conditions, whereas others focus too narrowly on non-technological factors, highlighting the need for more holistic assessment frameworks (Monshizadeh *et al.*, 2023). The literature also points to a shortage of scientifically developed and empirically validated readiness and maturity models (Wagire *et al.*, 2021), together with persistent problems of completeness and clarity, since some approaches rely on generic stage descriptions and insufficient specification of dimensions, enablers, variables, and assessment criteria, which hinders accurate assessment and weakens practical usefulness (Felippes *et al.*, 2022).

Beyond these conceptual and methodological limitations, readiness and maturity approaches may also face an important usability challenge in practice. Some models are methodologically complex to the point that their results require professional judgment for interpretation after application in organizational settings (Felippes *et al.*, 2022), whereas management-oriented frameworks should remain sufficiently user-friendly and should not depend on complex mathematical or statistical procedures for routine use in enterprises (Ramanathan; Samaranayake, 2022).

This broader limitation becomes especially relevant in the case of blockchain adoption. Although a small number of studies have addressed blockchain readiness more directly, the available approaches remain limited in their ability to support structured organization-level readiness diagnosis. Irannezhad *et al.* (2021), for instance, propose an analytically robust FCM-FBWM approach to assess and manage readiness for blockchain incorporation in supply chains, but its application depends on expert-driven elicitation, causal mapping, and weighting procedures that may restrict direct organizational use without methodological support. Balasubramanian *et al.* (2021) also propose a readiness assessment framework for blockchain adoption in a healthcare setting, from a stakeholder-oriented perspective, rather than as a standardized self-assessment instrument for organizations. Other studies address adjacent issues, such as the prioritization of blockchain readiness challenges in specific application domains, instead of providing a repeatable organization-facing readiness assessment instrument (Dwivedi *et al.*, 2023). Taken together, these studies suggest that blockchain readiness approaches remain scarce and that the few contributions closest to organizational assessment are either analytically demanding procedures or remain largely framework-oriented and context-specific. This highlights the need for a blockchain readiness model that is not only methodologically grounded but also practical, interpretable, and decision-oriented for use in real organizational contexts.

To address this problem, the thesis adopts an integrative and cumulative research design that progressively builds the final readiness model rather than proposing it in isolation. More specifically, it integrates evidence on blockchain adoption barriers, readiness requirements from the broader literature on emerging technologies, and relevant constructs from the technology adoption literature into an organizational readiness assessment model for blockchain adoption in supply chain contexts. The resulting model consolidates and validates a theory-grounded set of readiness requirements, organizes them under the Technology–Organization–Environment (TOE) framework, and operationalizes them into a replicable assessment artifact designed to support organizational self-diagnosis (DePietro; Wiarda; Fleischer, 1990; Tornatzky; Fleischer;

Chakrabarti, 1990). In addition, the thesis proposes an interpretable mechanism for aggregating multidimensional readiness into an overall readiness outcome, thereby supporting more informed adoption decisions. Methodologically, the study follows a Design Science Research (DSR) approach, iteratively designing and evaluating the proposed artifact through expert feedback and pilot application (Hevner *et al.*, 2004; Peffers *et al.*, 2007).

In this context, the thesis contributes by advancing theoretical understanding of organizational readiness for blockchain adoption in interorganizational settings, by moving methodologically from diagnosis to artifact design through a cumulative and design-oriented strategy, and by providing a practical assessment instrument to support pre-adoption decision-making.

From a practical standpoint, the thesis extends its contributions beyond the development of a readiness model by proposing two complementary technological products, outlined in Appendix E. The first is a conceptual proposal for a digital platform that would enable organizations to assess blockchain adoption readiness, generate structured diagnostic reports, and access benchmarking insights across different supply chain contexts. The second is a proposed application manual designed to provide guidance for conducting the assessment and interpreting its results. By outlining these potential tools, the thesis enhances its practical relevance and supports organizations in making more informed and structured blockchain adoption decisions.

In this context and with this motivation, the next section presents the objectives that guide the thesis.

1.2 Research questions and methodological overview

This section presents the research questions that guide the thesis and provides an overview of the methodological approach adopted in each article.

1.2.1 General objective and overarching research question

Based on the context presented above, this doctoral thesis is guided by the following overarching research question: How can readiness for blockchain adoption in supply chain networks be systematically understood, structured, and assessed to support organizational adoption decisions? In response to this research question, the central objective of this thesis is to advance the understanding and assessment of organizational readiness for blockchain adoption in supply chain networks and to translate this knowledge into a decision-oriented evaluation model.

1.2.2 Article-level research questions and methods

This thesis comprises four cumulative studies that collectively address the overarching problem of blockchain adoption readiness in supply chain networks. First, the thesis investigates the technological barriers that constrain blockchain adoption and the strategies proposed to mitigate them. Second, it examines non-technological barriers and the alignment between mitigation strategies and stakeholder characteristics in supply chain ecosystems. Third, it addresses the methodological problem of how readiness models for emerging digital technologies in operations and supply chain management should be designed and structured. Finally, it develops and evaluates an organizational readiness assessment artifact for blockchain adoption in supply chain networks. To operationalize these studies, the thesis employs systematic literature reviews, qualitative methods such as expert panels and focus groups, and fuzzy-logic-based modeling. The development and evaluation of the final artifact are conducted within a Design Science Research (DSR) approach.

Article 1 investigates the technological barriers companies face in adopting and using blockchain in supply chain operations, the mitigation strategies proposed to address them, and the stages of adoption at which these barriers and strategies emerge. To address these questions, the study employs a systematic literature review (SLR), followed by qualitative content analysis of the selected studies, and complemented by expert-based validation. The analytical procedure is interpreted through the lens of Diffusion of Innovations (DOI), allowing the study to identify technological barriers, map mitigation strategies, and position both across the stages of blockchain adoption.

The RQs addressed in Article 1 are:

RQ_1. What are the technological barriers faced by companies during the adoption and use of blockchain within their supply chain operations?

RQ_2. What are the recommended strategies to mitigate these barriers?

RQ_3. In the context of DOI theory, at which specific stages of blockchain adoption do the identified barriers and their corresponding mitigation strategies emerge?

Article 2 examines the non-technological barriers to blockchain adoption in supply chains, the strategies proposed in the literature to mitigate these barriers, and the alignment of such strategies with the needs and characteristics of stakeholders in the supply chain ecosystem. Methodologically, the study combines a preliminary scoping review with an SLR. The scoping review is used to identify broad themes and refine the research focus, while the SLR follows a structured protocol based on PRISMA recommendations. After article selection, qualitative content analysis is used to identify, categorize, and refine non-technological barriers and mitigation strategies. The study also incorporates expert validation and expert-panel review, which support the refinement of barrier categories, mitigation strategies, and the formulation of stakeholder-oriented research propositions.

The research questions addressed in Article 2 are:

RQ_4. What are the non-technological barriers to adopting blockchain in supply chains?

RQ_5. What strategies are proposed in the literature to mitigate these barriers?

RQ_6. How do these strategies align with the needs and characteristics of various stakeholders in the supply chain ecosystem?

Article 3 addresses the methodological problem of how readiness models for emerging digital technologies in operations and supply chain management should be designed and structured. To address this problem, the study develops a DSR-based reference architecture for readiness model design. Methodologically, the study adopts a multi-stage process. First, a systematic literature review, supported by content analysis of the selected studies, is used to establish the conceptual foundation and develop the initial framework. Second, expert interviews and focus groups are employed to refine and validate the framework. Third, an ex-ante demonstration is conducted to assess its applicability before real-world use. In this way, Article 3 not only identifies the essential components of readiness models but also provides a step-by-step development logic that incorporates Design Science Research requirements for artifact design, refinement, validation, and demonstration.

The research question addressed in Article 3 is:

RQ_7. What are the essential components and methodological steps for designing readiness models that support the adoption of emerging digital technologies in

Operations and Supply Chain Management, and how can these be integrated into a reference architecture?

Article 4 builds on the findings of the previous studies by addressing how a readiness assessment artifact can be designed, developed, and evaluated to support organizations in assessing readiness for blockchain adoption in supply chain networks. To address this problem, the study follows a Design Science Research (DSR) approach organized into three macro-phases: necessity assessment, model development, and readiness tool evaluation. The study combines item generation from prior barriers and theoretical constructs, expert-based refinement of dimensions and items, development of item-level and global readiness levels, design of a fuzzy inference system, formative validation of the rule base, sensitivity analysis, and a pilot application in a real organizational setting. Through iterative build–evaluate cycles, the study produces a validated organizational readiness instrument and an interpretable mechanism for overall readiness classification.

The research question addressed in Article 4 is:

RQ_8. How can a readiness assessment artifact be designed, developed, and evaluated to support organizations in assessing readiness for blockchain adoption in supply chain networks?

To answer RQ_8, the study examines:

(a) which core readiness conditions should be assessed;

(b) how these conditions can be operationalized and synthesized into an interpretable overall readiness outcome; and

(c) how iterative expert evaluation and a pilot application can refine the artifact and strengthen its practical utility.

1.3 Thesis Structure

The thesis is organized into eight chapters, as illustrated in Figure 1.1. The structure follows an article-based thesis format, in which four cumulative studies are progressively integrated to address the overarching research problem.

Figure 1.1 - Thesis Structure and Chapter Contributions

Chapter 1 - Introduction	*Defines the research problem, objectives, overarching research question, and cumulative dissertation logic.*
Chapter 2 – Blockchain fundamentals	*Establishes the blockchain adoption context in supply chain networks and its key interorganizational characteristics.*
Chapter 3 – Theoretical Integration	*Integrates relevant theories to frame blockchain adoption readiness in supply chain networks.*
Chapter 4 – Article 1	*Identifies technological barriers to blockchain adoption and their mitigation across adoption stages.*
Chapter 5 – Article 2	*Examines non-technological barriers and stakeholder-aligned mitigation strategies in supply chains.*
Chapter 6 – Article 3	*Develops a reference architecture for designing readiness models for emerging digital technologies.*
Chapter 7 – Article 4	*Designs and evaluates a readiness assessment artifact for blockchain adoption in supply chain networks.*
Chapter 8 – Conclusion	*Synthesizes findings and discusses contributions, limitations, and directions for future research.*

Source: Author's own work.

Chapter 1 serves as the introduction to the thesis. This chapter establishes the foundation for the research by presenting the background and motivation for the study, defining the research problem, objectives, and overarching research question, and outlining the methodological approach adopted. It also introduces the thesis's article-based structure and positions the individual studies within a cumulative research logic.

Chapter 2 presents the fundamentals of blockchain in supply chain contexts. This chapter provides a contextual and conceptual grounding for the subsequent studies by discussing the main characteristics of blockchain technology, its potential applications in supply chain networks, and the specific features that distinguish blockchain adoption from other digital technologies. Rather than offering a purely technical overview, the chapter emphasizes the interorganizational, relational, and governance-related aspects of blockchain that are particularly relevant to adoption and readiness discussions.

Chapter 3 addresses the research problem and develops the thesis's integrative theoretical foundations. This chapter discusses the need for a theory-driven approach to studying blockchain adoption readiness in supply chain networks and introduces the theoretical lenses used across the studies. By integrating perspectives such as Diffusion of Innovations, Stakeholder Theory, TOE, Organizational Readiness for Change, and Design Science Research, this chapter provides the conceptual rationale for the cumulative research design and clarifies how existing theories are consciously adapted to the specific context of blockchain adoption in supply chains.

Chapter 4 presents the thesis's first empirical study, which focuses on the technological barriers to blockchain adoption in supply chain operations. Through a systematic literature review and qualitative content analysis, this chapter identifies key technological barriers, examines the mitigation strategies proposed in the literature, and analyzes how both barriers and strategies relate to different stages of the adoption process. The analysis is interpreted through the lens of Diffusion of Innovations theory.

Chapter 5 extends the analysis of barriers to blockchain adoption by focusing on non-technological factors. This chapter examines organizational, environmental, and interorganizational barriers, as well as the strategies proposed to mitigate them. In addition, it analyzes how these strategies align with the needs, interests, and characteristics of different stakeholders within the supply chain ecosystem, thereby providing a more comprehensive and actor-sensitive understanding of adoption readiness.

Chapter 6 presents the third article of the thesis, which addresses the methodological problem of how readiness models for emerging digital technologies in operations and supply chain management should be designed and structured. This chapter develops a reference architecture for readiness model design based on a Design Science Research approach, integrating insights from the readiness and maturity literature with expert validation to define essential components and development steps.

Chapter 7 reports the fourth and final study, which builds on the findings of the previous chapters to design, develop, and evaluate an organizational readiness assessment artifact for blockchain adoption in supply chain networks. Following Design Science Research principles, this chapter operationalizes readiness conditions, develops an interpretable aggregation mechanism based on fuzzy logic, and evaluates the artifact through expert assessment and a pilot application in a real organizational setting.

Chapter 8 concludes the thesis by synthesizing the main findings from the four studies and discussing the research's theoretical, methodological, and practical contributions. This chapter also addresses the thesis's limitations and outlines directions for future research, including opportunities to further develop readiness and maturity perspectives on blockchain adoption in supply chain contexts.

2 BLOCKCHAIN FUNDAMENTALS FOR SUPPLY CHAIN MANAGEMENT

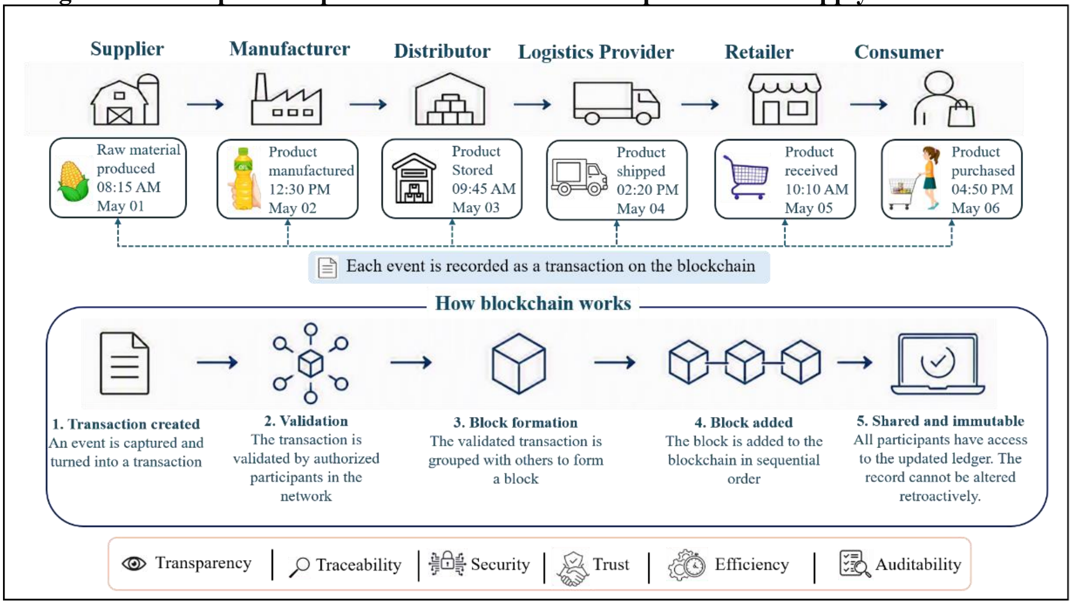
This chapter presents the fundamental concepts of blockchain technology as applied to supply chain management, highlighting its key characteristics and interorganizational implications. The discussion focuses on aspects of blockchain that are particularly relevant for adoption and readiness analyses in supply chain networks.

2.1 What is blockchain?

The blockchain concept, introduced by Nakamoto (2008), can be understood as a distributed digital ledger that records and validates transactions across a peer-to-peer network, allowing multiple participants to share and verify records without trusting on a single centralized database (Chittipaka; Kumar; Sivarajah, 2023; Khan *et al.*, 2023). Rather than relying on a single centralized database, blockchain stores information in chronologically linked blocks secured through cryptographic mechanisms, thereby supporting data integrity and making validated records difficult to alter (Khan *et al.*, 2023). In supply chain settings, these characteristics have attracted growing attention because blockchain may enhance transparency, traceability, security, and the reliability of shared records across organizational boundaries (Chittipaka; Kumar; Sivarajah, 2023).

An important feature of blockchain is that validated transactions are recorded with a unique sequence and timestamp, which helps preserve the chronological order of events and supports the traceability of transaction histories (Makridakis, 2019; Queiroz; Fosso Wamba, 2019). Because transactions are stored in cryptographically linked blocks, timestamps also contribute to the integrity and auditability of the ledger by facilitating the reconstruction and verification of recorded events over time (Queiroz; Fosso Wamba, 2019). In supply chain settings, this chronological recording is particularly relevant because it helps organizations monitor product- and process-related events across multiple actors and stages of the chain. In blockchain systems, new records are typically validated through consensus mechanisms, whereby participating nodes follow predefined rules to agree on the validity of transactions before they are appended to the shared ledger (Khan *et al.*, 2023; Wang *et al.*, 2025). Figure 2.1 provides a simplified illustration of how blockchain records and shares supply chain events across multiple actors.

Figure 2.1 - Simplified representation of blockchain operation in a supply chain network



Source: Author’s own work.

Figure 2.1 illustrates how blockchain can support information sharing across a supply chain. At each stage, supply chain actors record relevant events, such as raw material production, manufacturing, storage, shipment, receipt, and purchase. These events are transformed into transactions, validated by authorized network participants, grouped into blocks, and added sequentially to a shared and immutable ledger. This mechanism supports transparency, traceability, security, trust, efficiency, and auditability across the supply chain.

2.2 Public, private, and consortium blockchains

Blockchain networks can be broadly categorized into three main types: public, private, and consortium blockchains, which differ mainly in terms of openness, access restrictions, and governance arrangements.

A public blockchain is an open and permissionless network in which any participant can join the system, become a node, and contribute to transaction validation according to the protocol rules (Du *et al.*, 2020). Because no prior trust relationship is required among participants, public blockchains rely on decentralized consensus and a shared ledger to ensure the integrity, transparency, and immutability of recorded transactions (Du *et al.*, 2020; Magdy; Grida; Hussein, 2024). Compared with more restricted blockchain arrangements, public blockchains offer a higher degree of openness and decentralization, which makes them particularly attractive in contexts where transparency, traceability, and broad participation are valued (Magdy; Grida; Hussein, 2024).

A private blockchain is a permissioned blockchain network in which access is restricted to invited and validated participants (Giri; Manohar, 2023; Magdy; Grida; Hussein, 2024). In this type of network, existing participants or the network initiator can determine who is allowed to join according to predefined rules and requirements (Giri; Manohar, 2023). Compared with public blockchains, private blockchains offer greater control over participation and data access, and they do not necessarily require all nodes to validate every transaction, which allows network members to define validation responsibilities and business rules more selectively (Wang; Chen; Zghari-Sales, 2021).

A consortium blockchain is also a permissioned blockchain network, but governance is shared among multiple participating organizations. In this type of network, consensus nodes are predefined by the participating organizations, and transactions are confirmed by most of these nodes according to agreed rules (Du *et al.*, 2020). In supply chain contexts, this arrangement is particularly relevant because blockchain initiatives are often developed through consortia that allow members to control who can access the ledger and how the network is governed (Wang; Chen; Zghari-Sales, 2021). Compared with fully open blockchain arrangements, consortium blockchains offer more restricted access and a lower degree of decentralization, but they may provide advantages in terms of coordination, efficiency, and suitability for interorganizational business environments (Du *et al.*, 2020; Magdy; Grida; Hussein, 2024).

In supply chain settings, private and consortium-based blockchains are often more suitable than fully public networks because interorganizational collaboration typically requires controlled access, governance arrangements, and secure data sharing across participating firms (Xiong *et al.*, 2025). Although public blockchains offer important strengths in terms of decentralization, transparency, interoperability, and community participation, restricted-access blockchain arrangements may be more appropriate for business contexts in which confidentiality, coordination, and governance are critical (Magdy; Grida; Hussein, 2024).

2.3 Core properties and practical relevance of Blockchain for Supply Chains

Several blockchain properties make the technology especially attractive for supply chain applications. First, decentralization allows multiple actors to interact through a shared record without depending entirely on a single central intermediary, since blockchain operates through a distributed network in which records are maintained without reliance on a fully trusted central authority (Zhang; Yang; Liu, 2023). Second, immutability strengthens record integrity because validated transactions are linked to prior records and effectively locked into the blockchain ledger, making subsequent alteration difficult (Brau *et al.*, 2024). Third, transparency can improve visibility across supply chain relationships by supporting broader access to relevant product information among supply chain stakeholders (Sunny; Undralla; Madhusudanan Pillai, 2020) . Fourth, traceability enables the tracking of products, transactions, and events across the chain by supporting the capture and retrieval of product-related records, logistics data, and historical transactions throughout the supply chain (Ahmed; MacCarthy, 2023; Sunny; Undralla; Madhusudanan Pillai, 2020). Finally, provenance supports the verification of origin, which is particularly valuable in contexts where product authenticity, quality assurance, and compliance are important (Vazquez Melendez; Bergey; Smith, 2024).

These properties are particularly relevant because blockchain differs from the centralized information management systems that are still widely used in supply chains, such as enterprise resource planning (ERP) systems (Saberi *et al.*, 2019). By enabling data to be maintained and shared throughout a product's lifecycle across multiple actors, blockchain can function as a more trustworthy and tamper-evident record-keeping infrastructure, supporting nonrepudiation, immutability, and more reliable interorganizational data exchange (Azzi; Chamoun; Sokhn, 2019; Olsen; Tomlin, 2020; Tripathi; Ahad; Paiva, 2020). In addition, blockchain reduces dependence on centralized intermediaries by supporting decentralized coordination and transaction validation through consensus, while also enabling the verification of origin and the recording of ownership, timestamp, and location data as goods move across the supply chain (Abeyratne; Monfared, 2016; Kamble; Gunasekaran; Arha, 2019).

These characteristics help explain why blockchain has gained relevance in supply chain management. Because supply chains involve multiple organizations, fragmented information flows, and recurring challenges related to visibility, coordination, and trustworthiness of shared data, blockchain may support more reliable information sharing across organizational boundaries and strengthen transparency, traceability, and provenance. These capabilities are particularly relevant in contexts where it is important to verify origin, monitor product history, reduce informational disputes, and improve the credibility of shared records. These properties do not imply that blockchain is universally superior to conventional systems, but they help explain why the technology has attracted growing attention in supply chain management.

2.4 Implications for Blockchain Adoption Readiness

Although blockchain offers relevant opportunities for supply chain management, its adoption is not straightforward. The implementation of blockchain-based solutions involves more than the availability of the technology itself, as it also depends on how organizations manage data, coordinate with supply chain partners, and align governance arrangements across organizational boundaries.

In this sense, blockchain adoption requires a set of technological, organizational, and interorganizational conditions that may not be equally developed across firms and supply chain networks. Therefore, assessing whether an organization is ready to adopt blockchain becomes a necessary step before substantial implementation efforts are undertaken. This justifies the readiness perspective adopted in this thesis.

It is important to note that this thesis does not focus on organizational readiness for a single blockchain property or a narrowly defined application, such as transparency, provenance, or smart contract use in isolation. Although blockchain may be adopted with a more specific focal objective in some contexts, its potential value in supply chain settings is not limited to one feature alone. Blockchain combines multiple interrelated properties, and different firms within the same supply chain may prioritize different expected benefits depending on their position, processes, and strategic concerns. For this reason, the readiness model developed in this thesis adopts a broader perspective, aiming to assess organizational readiness for blockchain adoption in supply chain environments more generally rather than for one specific use case.

3 THE RESEARCH PROBLEM AND THE NEED FOR AN INTEGRATIVE THEORETICAL APPROACH

The central problem addressed in this thesis is the lack of robust decision-oriented instruments to assess whether organizations operating in Supply Chain environments are ready to adopt blockchain. The challenge is not only technological. It also involves organizational preparedness, interorganizational coordination, stakeholder alignment, and the ability to make sound adoption decisions before significant investments are made. The literature reviewed across the four papers shows that blockchain adoption in Supply Chains is affected by a wide range of barriers. This complexity means that blockchain adoption cannot be treated as a purely technical implementation issue. It must be understood as a multi-level organizational and interorganizational change process.

For this reason, the thesis is not built around a single theoretical lens, but around a set of complementary theories that address different dimensions of the same problem. Recent operations management (OM) research emphasizes the importance of grounding empirical studies in well-established theoretical lenses, particularly when investigating complex and emerging phenomena. Rather than relying on *ad hoc* constructs or purely data-driven explanations, scholars increasingly argue for the conscious adaptation of existing theories to new contexts, ensuring conceptual clarity and analytical rigor (Mtotywa; Mohapeloa, 2023). In line with this perspective, this thesis does not seek to develop a new theory of blockchain adoption. Instead, it deliberately combines and adapts several consolidated theoretical lenses, each addressing a distinct dimension of the adoption problem in Supply Chain contexts.

The four papers that compose this thesis reflect that broader logic. The first article investigates technological barriers to blockchain adoption in Supply Chains and uses the Diffusion of Innovations (DOI) theory to position such barriers and mitigation strategies along the adoption process. The second article addresses non-technological barriers through the lens of Stakeholder Theory, emphasizing the roles of different actors in overcoming these obstacles. The third article proposes a framework for developing Readiness Models in digital Operations and Supply Chain Management, drawing strongly on Design Science Research (DSR) and using DOI to clarify the distinction between readiness and maturity. The fourth article develops and validates a blockchain adoption readiness model for Supply Chains, structured through the Technology–Organization–

Environment (TOE) framework and Organizational Readiness for Change (ORC), and operationalized through a fuzzy inference mechanism.

A theory focused only on innovation adoption stages would not adequately capture the role of external actors and ecosystem coordination. A theory focused only on stakeholder relations would not explain when readiness should be assessed along the adoption journey. A framework for organizational contexts would not, by itself, explain how to build and validate an artifact. Likewise, a methodological paradigm alone would not provide the conceptual categories needed to define what readiness consists of. The thesis therefore adopts an integrative approach in which each theory addresses a specific aspect of the problem, while all of them converge in the design of the Readiness Model.

This integrative stance is especially important because the final goal of the thesis is not only to describe barriers to blockchain adoption, but to develop a useful assessment artifact. In other words, the thesis moves from understanding the adoption problem to designing a practical response to it. This movement (from diagnosis to design) requires conceptual breadth as well as methodological discipline. That is the rationale for combining DOI, Stakeholder Theory, TOE, ORC, DSR, and fuzzy logic within a single research program.

3.1 The role of each theoretical lens in the thesis

The purpose of this overview is therefore not to revisit each theory exhaustively, but to make explicit the role that each one plays within the broader logic of the thesis.

3.1.1 Diffusion of Innovations (DOI): understanding adoption as a process

The first theoretical foundation of the thesis is Rogers' Diffusion of Innovations (DOI) theory, which conceives innovation adoption as a process unfolding over time rather than as a single isolated decision. This process view is particularly relevant here because blockchain adoption in Supply Chains involves different moments of awareness, evaluation, decision, and implementation, each of which may raise distinct constraints.

Based on Rogers' Diffusion of Innovations (DOI) theory and its adaptations to organizational innovation adoption, especially the three-stage perspective advanced by Hameed, Counsell and Swift (2012) and subsequently applied to blockchain by Upadhyay (2020), this thesis uses DOI primarily as a process lens. More specifically, in Article 1, DOI supports the mapping of technological barriers and mitigation strategies across the stages of initiation, adoption-decision, and implementation. This process-based perspective clarifies not only the nature of these barriers, but also the moments at which they become most critical for firms considering blockchain adoption in Supply Chains. This temporal logic is not extended mechanically to all barriers examined in the thesis. Non-technological barriers are examined through Stakeholder Theory, since they are better understood in terms of actor roles, interorganizational dependencies, and institutional alignment.

DOI also plays a second and equally important role in the third article by helping distinguish Readiness Models from Maturity Models. As discussed in Article 3, readiness should be assessed before or during the early stages of implementation, when organizations are still deciding whether and how to adopt an innovation. Maturity, by contrast, refers to the level of development achieved once an innovation has already been implemented and routinized. This distinction is fundamental to the present study, as the proposed artifact is designed to support pre-adoption and early adoption decision-making rather than post-implementation assessment. Although blockchain has been implemented in several Supply Chain initiatives, recent studies point to persistent difficulties in sustaining and scaling these solutions across complex interorganizational networks (Najati, 2025). In this context, a focus on readiness assessment is more appropriate than maturity evaluation.

Accordingly, DOI provides the temporal logic of the thesis by clarifying when readiness assessment becomes relevant along the innovation journey and why such assessment is particularly important before large-scale implementation decisions are made.

3.1.2 Stakeholder Theory: explaining the interorganizational character of adoption

The second main lens is Stakeholder Theory, originally advanced by Freeman (1984), which argues that organizations must be understood in relation to the various groups and individuals who can affect or are affected by their actions. If DOI clarifies the temporal structure of adoption, Stakeholder Theory clarifies its relational structure. Blockchain adoption in Supply Chains is not an isolated firm-level event, but an inherently interorganizational process that depends on the participation and alignment of multiple actors across the Supply Chain network (Kouhizadeh; Saberi; Sarkis, 2021). By focusing on non-technological barriers, the second article shows that many of the obstacles to blockchain adoption are rooted in relationships among actors rather than in technology itself. The study identifies non-technological barriers grouped into intra-organizational, inter-organizational, and cost-related categories, and then links mitigation strategies to stakeholder roles. In doing so, it shows that successful adoption requires more than internal readiness: it also requires coordinated action among Supply Chain partners and other relevant actors in the broader ecosystem.

3.1.3 Technology–Organization–Environment (TOE): structuring the dimensions of readiness

A third important foundation is the Technology–Organization–Environment (TOE) framework, introduced by DePietro *et al.* (1990) and Tornatzky *et al.* (1990). TOE proposes that technology adoption is shaped by three broad contexts: the technological context, the organizational context, and the environmental context. Once this study establishes that blockchain adoption is both processual and interorganizational, it must define what exactly should be assessed when measuring readiness. This is where TOE becomes central. In the fourth article, TOE provides the main structural logic for organizing the Readiness Models into three complementary dimensions: technology, organization, and external environment. These dimensions reflect the broad set of conditions that shape adoption decisions and adoption feasibility.

The technological dimension captures issues related to infrastructures, systems, interoperability, and digital capabilities. The organizational dimension reflects internal characteristics such as leadership, resources, knowledge, culture, and implementation capacity. The environmental dimension captures external pressures and enabling conditions, including relationships with partners, regulation, and ecosystem support. This structure is particularly suitable for blockchain adoption in Supply Chains because the technology cannot be implemented successfully if one of these three fronts is ignored.

3.1.4 Organizational Readiness for Change (ORC): deepening the organizational dimension

While TOE offers a broad structural framework, Organizational Readiness for Change (ORC) adds depth to its organizational dimension. Drawing especially on Weiner (2009), ORC understands readiness as a shared organizational state involving both commitment to change and confidence in the collective ability to implement it. The fourth article uses ORC to capture the human and collective side of change. This is a critical move because organizational readiness is not only about having resources, systems, or formal capabilities in place. It also involves whether organizational members are committed to the change and believe they can carry it out successfully.

This perspective is highly relevant in the context of blockchain adoption. The first study itself shows that even technological barriers often have a strong human component, as they shape trust, reluctance, and perceptions of feasibility. ORC helps bring that organizational reality into the Readiness Model by accounting for change-related conditions such as change efficacy, organizational culture, established policies and procedures, and the organization's past experience with similar initiatives, all of which shape collective preparedness for implementation (Weiner, 2009). Rather than serving competing roles, TOE and ORC are integrated in the design of Readiness Model. TOE provides the core dimensional structure of the artifact and informs some of the readiness items associated with technological, organizational, and environmental conditions. ORC complements this structure by strengthening the organizational component of the model.

3.1.5 Design Science Research (DSR): moving from explanation to artifact design

The previous theories explain the phenomenon and structure the content of the model. The methodological backbone of the thesis is Design Science Research (DSR), especially as formulated by Hevner *et al.* (2004) and further operationalized in design-oriented research by authors such as Peffers *et al.* (2007). DSR explains how the knowledge developed through the theoretical lenses discussed above is transformed into an artifact. This is one of the most important theoretical-methodological moves in this study. The third article explicitly argues that DOI explains why Readiness Model is needed in innovation adoption, while DSR provides the logic for how such models should be designed in a rigorous and useful way.

This design logic continues in the fourth article, where the Readiness Model is developed and validated through iterative cycles of design, refinement, and evaluation. The artifact is not presented as an intuitive checklist, but as the product of a structured design process informed by theory, literature, expert input, and pilot testing. Collectively, this approach positions the present work as a design-oriented contribution aimed at generating a rigorously grounded and practically relevant solution.

DSR thus provides the methodological bridge through which multiple theoretical insights are systematically translated into a coherent, transparent, and usable assessment artifact.

3.1.6 Fuzzy logic: operationalizing multidimensional readiness

Fuzzy logic is not the main explanatory theory of the thesis, but it is an important operational mechanism in the fourth article. Its role is to synthesize multiple readiness conditions into an interpretable global readiness classification. This is particularly appropriate in a context where readiness is not binary and where the interaction among dimensions may be imbalanced, subjective, and non-linear.

In practical terms, the fuzzy inference system (FIS) allows the model to combine judgments across technological, organizational, and external environmental dimensions and translate them into a global readiness level (GRL). This reinforces the study’s commitment to an artifact that is both conceptually grounded and useful for diagnosis. Rather than flattening complex assessments into simplistic scoring rules, fuzzy logic preserves ambiguity and gradation, features that are often intrinsic to organizational readiness.

3.2 From adoption barriers to readiness requirements: an integrative derivation logic

This section explicates the conceptual logic through which adoption barriers and mitigation strategies identified in the first two studies (papers) of the thesis, together with constructs drawn from the TOE and ORC frameworks and prior readiness models, are translated into readiness requirements that inform the proposed readiness model. The aim of this section is not to replicate detailed literature reviews or methodological procedures reported elsewhere in the thesis, but to make explicit the derivation logic and traceability underlying the construction of the readiness requirements.

3.2.1 Adoption barriers as diagnostic inputs and their translation into readiness requirements

The first two articles of the thesis identify a total of 47 barriers to blockchain adoption in Supply Chain contexts, encompassing both technological and non-technological categories. These barriers constitute the initial diagnostic layer of the research, revealing where adoption efforts tend to encounter constraints, risks, or resistance.

However, not all identified barriers are relevant for an organizational readiness assessment. Some barriers, such as fork problems, immutability constraints, black-box effects, scalability limitations, and latency issues, are directly related to the technological maturity of blockchain solutions. These issues are primarily the responsibility of technology developers and infrastructure providers and therefore fall outside the scope of organizational and Supply Chain readiness assessment.

Consequently, a screening step was applied to distinguish barriers that are meaningful for assessing organizational and interorganizational preparedness from those reflecting purely technological immaturity. Importantly, this screening did not exclude technological barriers as a whole. Technological barriers that can be addressed through organizational capabilities, investments, or coordinated action at the supply chain level were retained as relevant diagnostic inputs for readiness modeling.

To move from diagnosis to assessment, the retained barriers were conceptually reframed into readiness requirements. This translation represents a deliberate analytical shift: from identifying obstacles that hinder blockchain adoption to defining positive, assessable conditions that organizations and Supply Chains should exhibit prior to or during early adoption.

In line with prior work on digital readiness modeling (e.g., Lokuge *et al.*, 2019), barriers were transformed into positive statements using antonyms or equivalent formulations. For example, barriers related to the absence of data governance mechanisms were reframed as requirements concerning the existence of clear data governance structures. Through this process, barriers ceased to function as negative descriptors of failure and instead became measurable indicators of preparedness for adoption.

Following this reframing and initial consolidation, 24 readiness requirements were derived directly from the refined set of adoption barriers. These requirements ensure that the readiness model remains empirically grounded in the adoption challenges identified in the blockchain in Supply Chains literature.

3.2.2 Complementary sources of readiness requirements

The derivation of readiness requirements in this thesis combines four complementary sources, each contributing a specific type of analytical grounding and together ensuring traceability, completeness, and conceptual coherence.

First, the refined adoption barriers discussed above contributed 24 readiness requirements, rooted directly in evidence on blockchain adoption challenges in Supply Chains. Nevertheless, adoption barriers alone are insufficient to represent the full set of organizational and interorganizational conditions required for blockchain adoption in supply chain contexts. For this reason, additional readiness requirements were incorporated from complementary sources.

Thus, a focused review of readiness model for emerging and digital technologies conducted in Article 3 provided a large pool of candidate requirements. From 26 reviewed studies, 167 readiness-related items were extracted. Although these items were derived from studies addressing a range of emerging technologies, not exclusively blockchain, they capture common readiness concerns that are sufficiently general to be extended to blockchain adoption in Supply Chain contexts and therefore serve as a methodological benchmark for readiness assessment.

The TOE framework contributed six constructs that inform the overall structuring of readiness dimensions and conditions related to technological capabilities, organizational context, and environmental factors. Examples of such constructs include centralization, the availability of internal slack resources, and government regulation. ORC contributed five constructs that capture key change-related aspects, including change commitment, change efficacy, organizational culture, established policies and procedures, and past experience, thereby strengthening the organizational dimension of readiness.

Taken together, these four sources yielded an initial universe of 202 raw candidate requirements (167 from prior readiness literature, 24 from barrier refinement, six from TOE, and five from ORC). These candidates were not treated as a final or operational set.

Instead, they constituted a comprehensive conceptual pool subjected to systematic refinement.

3.2.3 Refinement and consolidation of readiness requirements

Given the substantial conceptual overlap among candidate requirements drawn from different sources, multiple refinement steps were necessary to achieve parsimony, clarity, and relevance for organizational self-assessment. An internal refinement process was first conducted to combine semantically overlapping items, harmonize terminology, and standardize wording to ensure interpretability in an organizational readiness assessment context. This step recognizes that different strands of literature often use distinct terms to describe substantively similar readiness conditions.

Following this internal consolidation, the pool of candidate requirements was reduced to a manageable and theoretically coherent subset of 30 requirements. External refinement was then conducted through expert evaluation, as described in Article 4, to assess relevance and appropriateness for blockchain adoption readiness in Supply Chain contexts. Through this combined refinement process, the initial candidate set was ultimately consolidated into a final set of 26 readiness requirements, structured according to the technological, organizational, and external-environment dimensions of the TOE framework.

3.2.4 Readiness requirements as a bridge between diagnosis and design

Within the overall research logic of the thesis, readiness requirements occupy a central intermediary role, linking the diagnosis of adoption challenges to the design of a decision-oriented assessment artifact. By explicating how barriers, theoretical constructs, and prior readiness models converge into readiness requirements, this section shows that the proposed readiness model results from a structured and transparent derivation process. These readiness requirements directly inform the construction of the readiness model developed and validated in the fourth article, where DSR provides the methodological logic for transforming consolidated requirements into a usable and rigorously grounded artifact.

3.3 Integrating the four studies: from barriers to artifact

The four studies of the thesis are best understood as cumulative and sequential rather than independent. Taken together, they form an integrated research program that explicitly connects problem diagnosis, readiness requirement derivation, and artifact design. Each theoretical and methodological foundation is employed because it contributes insights that the others do not fully explain on their own, while collectively supporting the development of a coherent readiness assessment artifact.

As discussed in the previous section, readiness requirements constitute the conceptual bridge between the identification of adoption barriers and the design of a decision-oriented assessment model. Together, these theoretical and methodological foundations address complementary aspects of the blockchain adoption problem and converge in the development of the readiness artifact. DOI defines the temporal scope of readiness assessment, Stakeholder Theory captures the interorganizational nature of adoption, TOE and ORC structure and deepen the readiness construct, and DSR guides the transformation of these insights into a rigorously designed artifact. Fuzzy logic subsequently enables the operational synthesis of readiness conditions into an interpretable assessment outcome.

Table 3.1 summarizes the analytical role of the main theoretical and methodological foundations used throughout the thesis. The table clarifies how each element contributes to the overall logic of the study and to the development of the readiness artifact.

Table 3.1 - Analytical role of the main theoretical and methodological foundations used in the thesis

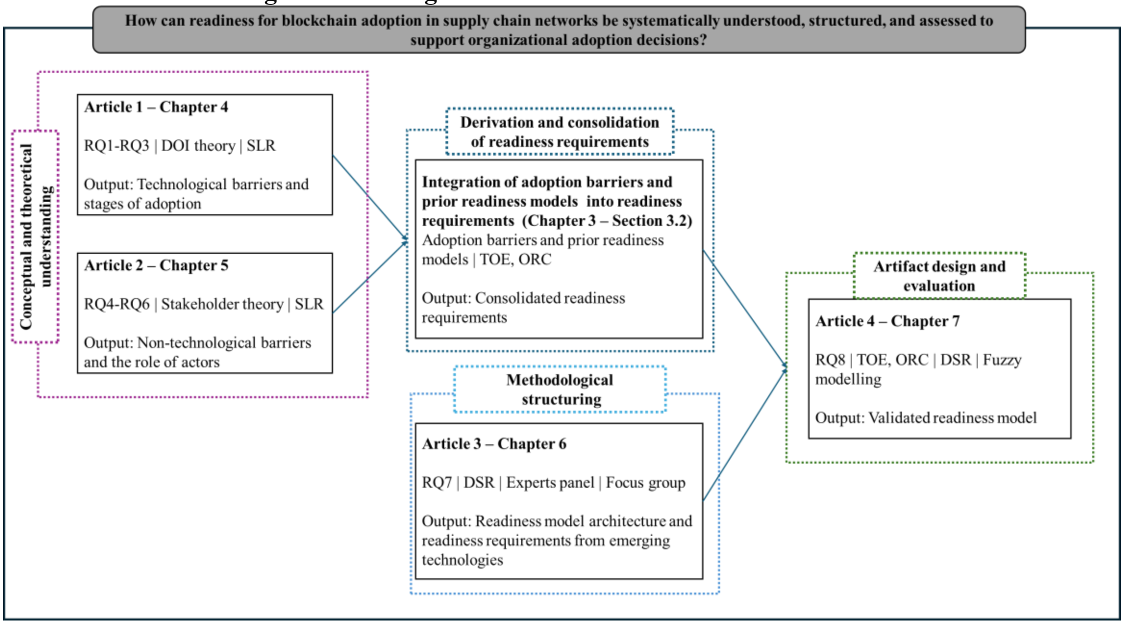
Element	Analytical role in the thesis	Specific contribution to the thesis	Main location in the thesis
DOI	Process lens	Clarifies the temporal dimension of blockchain adoption. In Article 1, it supports the positioning of technological barriers and mitigation strategies across the stages of initiation, adoption-decision, and implementation. In Article 3, it also helps distinguish readiness from maturity.	Articles 1 and 3
Stakeholder Theory	Relational and interorganizational lens	Explains the role of actors, dependencies, and coordination in overcoming non-technological barriers across the SC ecosystem.	Article 2
TOE	Structural lens for readiness assessment	Organizes the RM around technological, organizational, and environmental domains, while also informing some of the readiness conditions assessed within those domains.	Article 4
ORC	Organizational change lens	Deepens the organizational dimension of the RM by incorporating change-related aspects such as commitment, willingness, and perceived implementation capability.	Article 4
DSR	Artifact design logic	Provides the methodological logic for developing, refining, and validating the readiness artifact.	Articles 3 and 4
Fuzzy logic	Aggregation mechanism	Supports the operational synthesis of multiple readiness conditions into an interpretable overall readiness outcome.	Article 4

Source: Author's own work.

Taken together, these foundations provide coherence to the thesis and support the development of the proposed readiness artifact.

Figure 3.1 presents an integrative overview of the thesis. It illustrates how the four studies are cumulatively connected, how different theoretical lenses and methods are mobilized at each stage, and how empirical evidence on adoption barriers is progressively translated into a validated readiness assessment artifact.

Figure 3.1 - Integrative research framework of the thesis



Source: Author’s own work.

4 OVERCOMING TECHNOLOGICAL BARRIERS FOR BLOCKCHAIN ADOPTION IN SUPPLY CHAINS: A DIFFUSION OF INNOVATION (DOI)-INFORMED FRAMEWORK PROPOSAL (Paper 1[1])

This chapter examines technological barriers to blockchain adoption in supply chains and the strategies proposed to mitigate them. Using Diffusion of Innovations theory, it analyzes how these barriers and strategies unfold across adoption stages and proposes a DOI-informed framework for understanding technological readiness.

4.1 Introduction

The adoption of blockchain in Supply Chain Management (SCM) is markedly hindered by a lack of well-documented use cases, field experiences, and clear insights into blockchain trial outcomes. This challenge is further compounded by the limited literature addressing the technological barriers to blockchain adoption, as highlighted by Hackius and Petersen (2020), Queiroz *et al.* (2019), and Dutta *et al.* (2020). This occurs even though many companies are actively developing and testing various prototypes. For example, the recent announcement of the discontinuation of TradeLens operations, joint initiative by A.P. Moller - Maersk and IBM for Supply Chain digitization, reinforced that the successful implementation of blockchain implies overcoming obstacles that limit its adoption.

While our study primarily examines the barriers to the adoption of blockchain, it is important to emphasize that our objective is not to demonstrate how these barriers impede the adoption of blockchain or to argue against the viability of this technology. Our objective is to provide readers with information regarding the actual existence of these barriers and strategies to overcome them. Multiple recent research has documented a series of successful blockchain implementations (Adel; Younis, 2023; Alkafaji; Dashtbayaz; Salehi, 2023; Bag *et al.*, 2023; Chittipaka; Kumar; Sivarajah, 2023); Sumarliah *et al.*, 2023).

The availability of successful implementations is likely associated with the existence of strategies to overcome existing barriers. Increasing the amount of knowledge regarding current barriers, the specific point in the process of adopting blockchain when

[1] This article has been published in Supply Chain Management: An International Journal. DOI: 10.1108/SCM-02-2024-0138

they occur, and the strategies that can be used to reduce their impact, can significantly enhance the quality of literature on blockchain adoption. Therefore, a study that sheds light so that companies and researchers know what they are dealing with when they decide to adopt blockchain becomes essential to contribute to the continued development of blockchain applications in Supply Chains.

Recognizing the critical need for a deeper understanding of these impediments, this study embarks on a systematic exploration of both the technological barriers to blockchain integration in Supply Chain Management and the strategies identified in the literature to surmount these obstacles. Our research extends beyond merely cataloguing the advancements and general barriers to blockchain adoption. We aim to provide a detailed examination of the specific technological barriers within the Supply Chain Management context and to organize the strategies found in the literature that address these barriers, using the Diffusion of Innovation (DOI) theory as a guiding framework. This comprehensive analysis is facilitated through a multifaceted approach that combines a Systematic Literature Review (Tranfield; Denyer; Smart, 2003) with rigorous content analysis (Krippendorff, 2019) and insightful expert interviews. This triangulation method enriches our understanding of the barriers and enhances the robustness of the strategies we identify, ensuring they are grounded in theoretical and practical insights.

The objective of this study is to provide novel insights that can be applied in both practical and theoretical contexts. It does so by integrating disparate themes, such as barriers and mitigation strategies, with the stages of technology adoption. The main goal is to gain a more comprehensive understanding of the limitations that impede the adoption of blockchain and how to overcome them. In contrast to other literature reviews, our study not only summarizes the barriers to blockchain adoption but also explores and discusses strategies to mitigate them. In addition, the application of a theoretical lens enables a more accurate contextualization and interpretation, as well as a more robust conceptual foundation for the SLR results within a particular structure, such as the stages of innovation adoption, as per DOI theory. Additionally, our review suggests a well-defined research agenda for the future.

The literature suggests that research be conducted examining the barriers to blockchain adoption in this field. Rogers (2003) states that the innovation-decision process involves uncertainty about the expected consequences, and to deal with this, the decision-maker seeks to answer questions such as: "What operational problems am I likely to encounter, and how can I solve them?". A theoretical view is necessary to understand better the underlying motivators and barriers that will lead Supply Chain managers or discourage them from adopting blockchain (Francisco; Swanson, 2018). In this regard, it is important to employ a consolidated theoretical lens that enables us to comprehend the phases of blockchain adoption more systematically. The Diffusion of Innovation (DOI) theory (Rogers, 2003) was implemented in this study. This theory views the adoption of technology as a process that is characterized by a sequence of steps that occur over time. Consequently, it enables us to identify the specific moment in the adoption process at which companies will face blockchain implementation barriers and when mitigation strategies will become necessary.

Future studies should examine barriers and success factors in the blockchain adoption process (Schmidt; Wagner, 2019). Queiroz *et al.* (2019) and Dutta *et al.* (2020) recognize that a comprehensive examination of the challenges that limit the adoption of blockchain in Supply Chain Management is a research gap. Our study intends to help better understand these underlying barriers, specifically the technological ones. Consequently, we formulated the subsequent Research Questions (RQs) to direct our investigation:

RQ_1: What are the technological barriers faced by companies during the adoption and use of blockchain within their SC operations?

RQ_2: What are the recommended strategies to mitigate these barriers?

RQ_3: In the context of the Diffusion of Innovation (DOI) theory, at which specific stages of blockchain adoption do the identified barriers and their corresponding mitigation strategies emerge?

This study makes contributions in different ways: (*i*) it describes a complete and exhaustive list of technological barriers to blockchain adoption in Supply Chain Management, including privacy, scalability and security issues, lack of interoperability, and immutability; (*ii*) It suggests a discussion regarding the strategies for overcoming technological barriers that emerge during the three critical stages of technology adoption, defined using the lens of DOI theory. Based on DOI theory, the decision to embrace a technology does not happen instantaneously but rather unfolds gradually over a period of time. DOI theory allows for the precise definition of the activities carried out at each stage of the technology adoption process. This provided us with the foundation for constructing our framework. In this manner, we offer a roadmap for industry practitioners to develop actionable strategies for successfully traversing the blockchain adoption process. This comprehensive analysis represents a valuable result for the Supply Chain Management field, filling a considerable gap in the literature, especially by integrating these barriers and relevant solutions.

The paper is organized into 5 sections. Section 4.2 provides the theoretical background. Section 4.3 describes the research methodology. Section 4.4 presents the findings and discussion. Section 4.5 summarizes the conclusions of this research, academic and practical contributions, and proposes a future research agenda.

4.2 Conceptual and Theoretical background

This section provides the conceptual and theoretical background underpinning this study. It introduces the Diffusion of Innovation theory as the primary theoretical lens and explains how its adaptations to organizational IT and blockchain adoption support the structuring of the adoption process into stages and activities.

4.2.1 Diffusion of Innovation Theory

Researchers study organizational adoption using various theories to discern the factors influencing innovation acceptance across different IT adoption contexts (Frambach; Schillewaert, 2002). There is no single theory of innovation, nor does it seem likely that one will emerge (Fichman, 2000). Adoption decisions occur at two levels: the organizational level (by the organization itself) and the individual level (within the organization) (Frambach; Schillewaert, 2002).

Among the most used theoretical models at the organizational level are the Diffusion of Innovation theory (DOI) (Rogers, 2003), the Technology-Organization-Environment (TOE) framework (DePietro; Wiarda; Fleischer, 1990; Tornatzky; Fleischer; Chakrabarti, 1990) and, at the individual level, the Theory of Reasoned Action (TRA) (Fishbein; Ajzen, 1977), the Technology Acceptance Model (TAM) (Davis, 1989), and the Theory of Planned Behavior (TPB) (Ajzen, 1991).

Blockchain constitutes a technological innovation (Swan, 2015). Thus, theories concerning IT innovations are applicable to studies on blockchain adoption. A similar association, i.e., between IT innovation adoption and technology adoption, was previously made by (Hameed; Counsell; Swift, 2012). Theories and models that address IT innovation adoption are being used in studies that investigate the adoption of blockchain in the Supply Chain context, such as DOI theory (Nath *et al.*, 2022), TOE framework (Clohessy; Acton, 2019), TAM (Queiroz; Fosso Wamba, 2019), among others.

Other blockchain studies used DOI lenses. A multi-stage adoption model for a better understanding of blockchain diffusion across Supply Chains was proposed, based on DOI as one of its main theories (Queiroz *et al.*, 2019). Agi and Jha (2022) used the lens of the DOI to identify enablers of blockchain adoption and develop a comprehensive framework for blockchain adoption in the SUPPLY CHAIN. Rogers' classical model of diffusion represents the closest attempt to formulate a general theory for innovation adoption (Rogers, 2003). Consequently, our study will utilize the DOI as the primary theory to elucidate the adoption stages of blockchain.

According to the DOI theory, the innovation-decision process is the process by which the decision-maker goes through the stages of obtaining initial knowledge of an innovation, forming an attitude towards the innovation, deciding to adopt or reject, implementing the new idea, and confirming this decision (Rogers, 2003). This process consists of five stages: Knowledge, Persuasion, Decision, Implementation, and Confirmation.

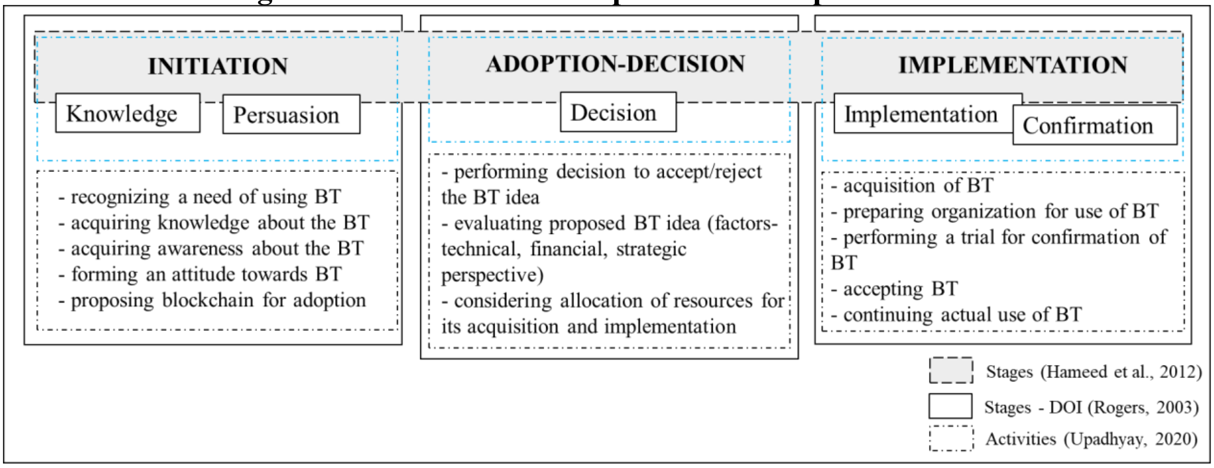
In the Knowledge stage, the decision-making unit is exposed to innovation and understands how it works. Persuasion is the stage in which information about the new idea is actively sought, intending to form a favorable or unfavorable attitude towards it. In the decision stage, activities are carried out that will lead to a choice to adopt or reject the innovation. Implementation is the stage where the innovation is put to use. It involves an evident change in behavior, as the new idea is put into practice. At the confirmation stage, the aim is to reinforce an innovation decision already taken, and in conflicting cases, to discontinue due to replacement or disenchantment that may occur.

According to the DOI theory, “each stage in the innovation-decision process is a potential rejection point.” This implies that a blockchain adoption project, being a technological innovation, can be rejected at any of these five stages. This occurred in the case of TradeLens, an effort that targeted end-to-end Supply Chain digitalization and was jointly undertaken by A. P. Moller Maersk and IBM. This platform operated effectively for 5 years, and after surviving the Knowledge, Persuasion, Decision, and Implementation stages, it was discontinued at the Confirmation stage due to collaboration challenges between Supply Chain partners.

Innovation adoption is deemed successful when the innovation is accepted, embraced, and integrated into the organization, and individuals consistently continue to use it over an extended duration, as stated by Gopalakrishnan and Damanpour (1997) and Upadhyay (2020). Given the possibility of blockchain adoption being rejected at any point in the innovation adoption process, it is necessary to conduct studies that shed light on the main challenges and barriers that could emerge at each of these stages. More importantly is to highlight the actions that firms implementing blockchain should take to overcome these barriers at the appropriate times so the initiative for blockchain adoption is successful and not interrupted. This demonstrates the significance of this research, which attempts to outline the barriers and strategies for overcoming them at each stage of the innovation adoption process. The DOI theory will be used as the foundation for these stages.

Hameed, Counsell and Swift (2012) proposed a conceptual model for IT innovation adoption. Despite referring to other models and theories, such as the TOE Framework, TPB, TAM, and TRA, among others, the authors used the DOI as the main basis for defining 3 stages in the process of adopting innovation at the organizational level: Initiation, Adoption-decision, and Implementation. Upadhyay (2020), based on the conceptual model proposed by Hameed, Counsell and Swift (2012), created a framework that guides the blockchain adoption process by organizations. In this framework, Upadhyay (2020) lists the activities necessary for adopting blockchain within the 3 stages presented in the conceptual model by (Hameed; Counsell; Swift, 2012). In addition to the DOI theory, our study will be based on the adaptations to this theory made by Hameed, Counsell and Swift (2012) and Upadhyay (2020) for the proposal of our framework, using these three stages: Initiation, Adoption-decision, and Implementation. Figure 4.1 shows the relationship between the stages of DOI theory, the stages proposed by Hameed, Counsell and Swift (2012), and the activities proposed by Upadhyay (2020).

Figure 4.1 - Blockchain Adoption-decision process



Source: Author's own work.

4.2.1.1 Initiation stage of adopting blockchain

Upadhyay (2020) states that during the initial phase of implementing blockchain, the organization becomes conscious of the necessity to utilize blockchain. This need may be driven by challenges or opportunities in its processes, which could be advantageous with the use of blockchain. For instance, the organization might have challenges related to trust, transparency, or security that could be effectively addressed by utilizing the immutability features offered by blockchain (Kumar Singh *et al.*, 2023).

After identifying this need, firms strive to comprehend the underlying principles associated with blockchain. This entails comprehending the intricacies of data storage, validation, security mechanisms, and the various types of blockchain, including public, private, and hybrid. Once firms understand the technical aspects of blockchain, they seek to familiarize themselves with its real-world use cases across various industries. By doing a thorough investigation of use cases, the advantages of blockchain may be uncovered and demonstrated to its users (Behnke; Janssen, 2020).

Once firms have comprehended the technological intricacies and acquired a level of familiarity with blockchain, they may evaluate its suitability in addressing the challenges that they encounter and develop a positive or negative attitude towards the technology. At this initial stage, if the organization develops a positive attitude towards implementing blockchain, it may suggest its adoption. This step entails discerning the specific opportunities within the firm where the technology can be efficiently utilized. Specifically, the corporation is starting to develop a more concrete attitude toward technology in the context of its operations.

4.2.1.2 Adoption-decision stage

During the adoption-decision stage, as stated by Upadhyay (2020), the organization performs three distinct activities. The initial action is to decide whether to accept or reject the use of blockchain. Having a favorable attitude towards an innovation does not necessarily result in the decision to adopt it (Rogers, 2003). At this stage, the company must make a careful decision by evaluating the alignment of blockchain with its strategic objectives, assessing the cost-benefit ratio of implementation, and comparing the substantial advantages of blockchain with other available solutions.

The second activity at this step involves assessing the proposed blockchain based on technical, financial, and strategic criteria. An in-depth examination of these three aspects enables the organization to ascertain the viability and potential impacts of using blockchain. In the third activity to be performed at this stage, the organization will determine the required resources for acquiring and implementing blockchain. These resources encompass both financial and human investments required to acquire, implement, and maintain blockchain operating in the organization. Prioritizing the assessment of return on investment (ROI) is essential since blockchain should be self-sustaining; otherwise, its implementation would not be justified (Mundra, 2018; Prasad *et al.*, 2018).

4.2.1.3 Implementation stage

At this stage, the organization transitions from making creative decisions and generating ideas to implementing technology, which involves a more bureaucratic approach (Rogers, 2003). The initial activity in this stage involves preparing for the acquisition of blockchain. This involves establishing contractual agreements with blockchain provider businesses (if the solution development is outsourced) or finalizing revisions with the internal solution development team (if the organization chooses to develop the solution in-house). At this point, it is crucial to provide adequate integration with the organization's current systems (interoperability), and precisely establish implementation prerequisites, such as specific features, security, and performance requirements.

Subsequently, the organization must make necessary arrangements to accommodate the utilization of blockchain. For the successful integration of their daily activities and functions with blockchain, employees, and stakeholders must undergo preparation to acquire the necessary skills to efficiently utilize the new technology (Ghode *et al.*, 2020; Queiroz; Fosso Wamba, 2019). To effectively utilize blockchain, the organization must obtain relevant expertise and establish the necessary infrastructure to accurately assess its existing resources and determine their intended use. The available alternatives include providing training to the current team, as well as employing new personnel, or outsourcing the required tasks (Wong *et al.*, 2020a).

During the third activity of this stage, the organization is required to conduct a test before the complete implementation of the technology. This test is often conducted through either a pilot test or a Proof of Concept (PoC) (Bourlakis; Seuring, 2022). This activity is conducted to validate the functionality of the technology in a smaller and controlled environment and to assess performance, user-friendliness, interoperability, and key difficulties encountered by employees (Bourlakis; Seuring, 2022).

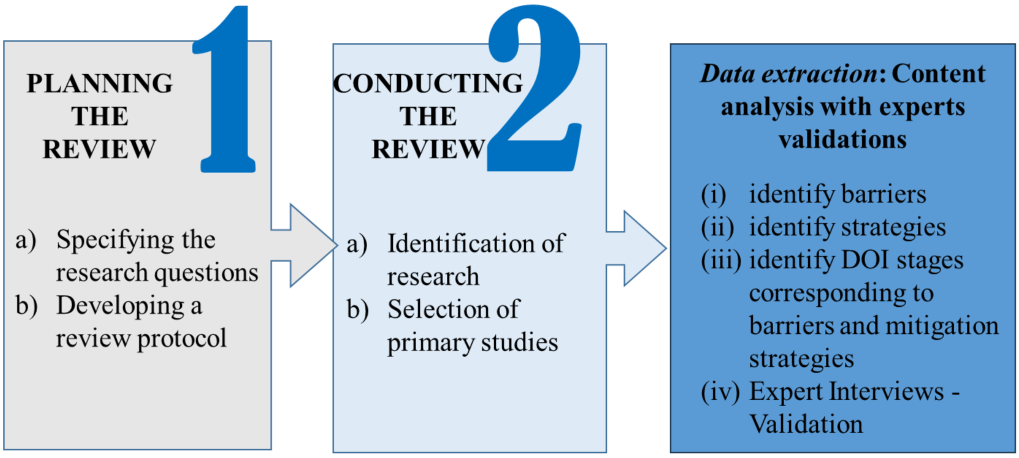
After evaluating blockchain 's performance during the testing phase, if the results are satisfactory, the organization must decide whether it will officially accept blockchain. In this manner, the organization can formalize blockchain 's approval for its full use in all of its operations. Finally, the company will be able to continue utilizing the technology in its operations. It is crucial to emphasize that, as previously mentioned, the decision to discontinue the use of the innovation may be made due to disenchantment or replacement in conflicting cases during the confirmation stage (Rogers, 2003).

Consequently, we highlight the significance of meticulously examining the barriers and strategies for their mitigation, while also considering the criticality of each of these phases and activities, which may serve as indicators of the abandonment of the innovation concept.

4.3 Research method

Our research methodology employs a comprehensive and integrated approach, combining Systematic Literature Review (SLR), content analysis, and expert interviews (Figure 4.2). This methodological triangulation ensures a deep understanding of the subject. We detail this approach in the next sections.

Figure 4.2 - Research methodology: SLR, content analysis, and expert validation



Source: Author's own work.

4.3.1 Systematic Literature Review

This SLR process is based on the process defined in Tranfield, Denyer and Smart, (2003) and Kitchenham and Charters (2007). The review protocol was developed based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations (Moher *et al.*, 2015).

4.3.1.1 Planning the review

In the *planning* step, we first defined the articles' research questions (RQs), which will drive the entire systematic review methodology (Kitchenham; Charters, 2007). Three RQs were proposed in the introduction section.

The review protocol, essential for systematic reviews, ensures thorough planning and documentation, reducing researcher bias and aligning with PRISMA recommendations (Kitchenham; Charters, 2007; Moher *et al.*, 2015). It includes research topics, search strategy, and inclusion/exclusion criteria. Our review protocol specified the scientific databases, aligning with Webster and Watson's suggestion that leading journals are key information sources (Webster; Watson, 2002). Hence, Web of Science and Scopus were selected for their extensive journal coverage (Gavel; Iselid, 2008; Singh *et al.*, 2021), while Engineering Village, the central platform for Compendex, was chosen for its comprehensive engineering literature (Dressel, 2017). The three databases mentioned are commonly utilized in contemporary literature reviews within the field of Operations Management (OM) and Supply Chain Management, as the studies conducted by Corallo *et al.* (2024), Saihi, Awad and Ben-Daya (2023), Vazquez Melendez, Bergey and Smith (2024), and Swink *et al.* (2024).

We conducted pilot searches to define search terms, observing that articles addressing barriers may not explicitly mention terms like "barrier," "challenge," or "obstacle." Instead, they may use various terms. To avoid limiting results, we opted for words related to blockchain and the context of our study (OM and SC&L). The sets of keywords and search strings used to search for articles in the databases are presented in Table 4.1.

The review protocol also established inclusion/exclusion criteria. Articles meeting the following conditions presented in Table 4.1 were included.

Table 4.1 - Search terms, data base and include criteria

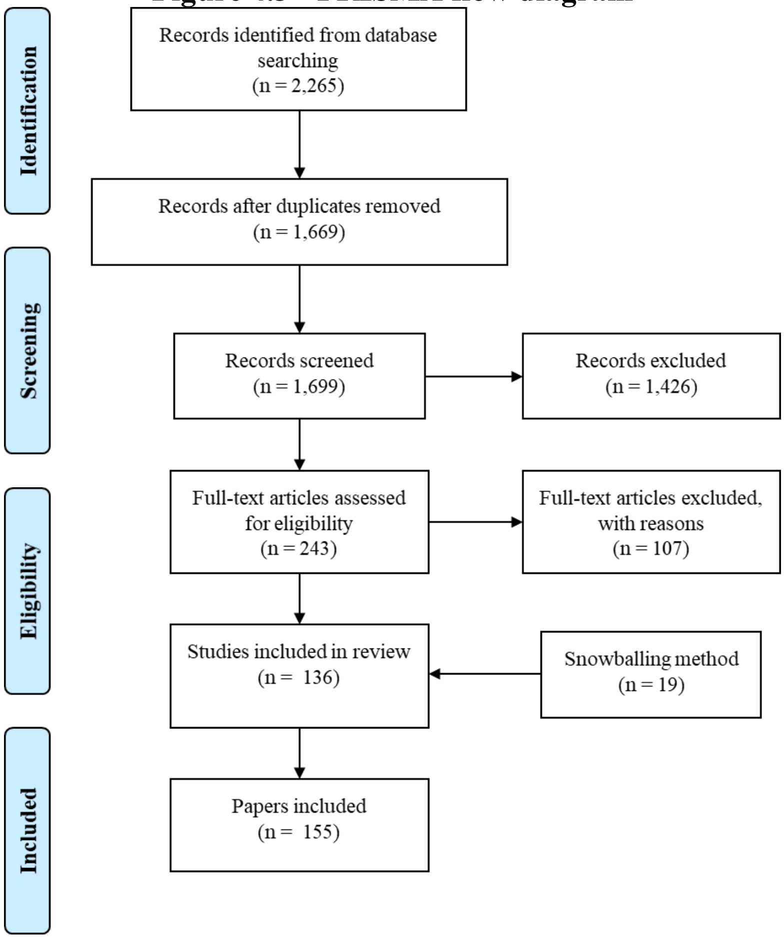
Parameters	Description
Keywords	"Blockchain," "BCT," "Distributed Ledger Technology," and "DLT," and another set focusing on the study context, encompassing terms like "supply chain," "value chain," "supply network," "operations," "management," "production," "logistics."
Databases	Web of Science, Scopus, Engineering Village.
Search strings	("blockchain" OR "BCT" OR "distributed ledger* technology" OR "DLT") AND ("supply chain" OR "value chain*" OR "supply network*" OR "management" OR "operations" OR "production" OR "logistics").
Inclusion criteria	(1) articles addressing limiting factors to blockchain adoption in SCM and mitigation strategies, (2) articles published in journals, (3) articles written in English, and (4) articles accessible in full

Source: Author's own work.

4.3.1.2 Conducting the review

In the *conducting* step, we performed searches in the databases, using the review protocol, and 2,265 articles were initially obtained. 596 duplicate papers were removed (see Figure 4.3).

Figure 4.3 - PRISMA flow diagram



Source: Author's own work.

As not all the remaining 1,699 articles were necessarily related to our RQs, assessing their relevance through an article screening process was necessary. In screening relevant papers, the 1,669 articles were initially analyzed based on title, abstract, and keywords. The review protocol returned articles with a purely technical, mathematical, and computing science focus, which was clearly out of the scope of our study; thus, we excluded them. In some cases, it was difficult to analyze the article's relevance just by reading the title, abstract, and keywords. In this case, we passed it through to the next stage for further reading, allowing us to retain as many relevant articles as possible. Two reviewers conducted this screening to decrease subjectivity in the choice. In this phase, 1,426 papers were rejected, and 243 papers were retained for a full review. The papers approved in all 4 inclusion criteria mentioned in the review protocol were selected for the next step.

4.3.2 Content Analysis with Expert Panel Validation

In our research, we meticulously employed content analysis (CA) (Krippendorff, 2019), as an essential technique to identify technological barriers to blockchain adoption, the strategies proposed in the literature to mitigate these barriers, and the stages of blockchain adoption, as delineated by the Diffusion of Innovation (DOI) theory, where these elements manifest. This comprehensive coding process was conducted using Nvivo software, which allowed us to systematically organize and analyze the content of the selected papers. Through this method, we could distill the vast array of information into manageable codes, facilitating a granular examination of the barriers and strategies within the context of blockchain adoption stages. This process enhances our analysis's precision and depth.

For this coding, we first selected the categories that would be analyzed in each article. To define these categories, we first conduct a keywording step. Other blockchain studies conducted keywording by reading the abstract (Mazlan *et al.*, 2020; Yli-Huumo *et al.*, 2016). As our central research topic is related to technological barriers, the abstract would not always reveal relevant terms. We found that the papers can mention and discuss barriers in other fields of work, even though this is not the final objective of the study. Thus, the keywording was conducted differently, i.e., through an exploratory analysis of 15 articles that mentioned the term barriers or challenges in the title, to generate an initial list of keywords to guide the identification process. These 15 studies were part of the 243 articles selected for the full review. We used the keywords found in this step to form the analyzed categories.

After defining the categories, we conducted a material evaluation step, in which all selected articles were analyzed according to the dimensions established in the category selection. After this full review, we noticed that 107 articles did not address topics related to our research theme. Therefore we excluded them from our sample, and 136 articles were retained, and another 19 were included using the backward snowballing method described by Wohlin (2014). Thus, a total of 155 articles were comprehensively analyzed utilizing CA. This process allowed new keywords to emerge and to be added to the initial categories. The coding cycles were repeated whenever a new relevant keyword appeared.

To ensure the validity and robustness of our findings derived from the coding process, we engaged in a two-tier validation process involving both PhD students and academic experts. Initially, our findings, including the identified barriers, strategies, and their corresponding stages of emergence within the DOI framework, were presented to 16 PhD students in Industrial Engineering, who are involved in the fields of Operations Management (OM) and Supply Chain Management (SCM). This preliminary review by the doctoral candidates served as a pre-refinement step, providing fresh insights and perspectives that contributed significantly to the organization and clarity of our analysis.

Following this initial validation, we further subjected our findings to a rigorous review by four academic experts, as detailed in Table 4.2. This involved a combination of written assessments and in-depth discussions during scheduled meetings, allowing for a comprehensive critique of our methodology and outcomes. Through individual interviews with each expert, we meticulously reviewed the initial categorization of barriers, strategies, and their stages of emergence based on the DOI theory. This expert review process validated the accuracy of our coding and offered opportunities for reassignment and refinement based on expert consensus, revealing intricate interconnections among the adoption stages. This dual-layer validation process, encompassing both PhD students and academic experts, was instrumental in reinforcing the credibility and reliability of our research findings. It ensured that our systematic categorization of barriers, mitigation strategies, and their DOI theory-based staging was grounded in the literature and resonated with current academic thought and practical insights.

Table 4.2 - Profile of experts

Expert	Position	Academic education	Research area of expertise	Experience with blockchain
1	Researcher/ Professor	PhD in Industrial Engineering	Operations Management and Supply Chain Management	5
2	Researcher/ Professor	PhD in Industrial Engineering	Operations Management and Supply Chain Management	5
3	Researcher/ Professor	PhD in Industrial Engineering	Operations Management and Supply Chain Management	5
4	Researcher/ Professor	PhD in Engineering	Operations Management and Supply Chain Management	6

Source: Author’s own work.

4.4 Results and discussion

Previous research has pointed out that technological barriers are only one type of barrier, together with other challenges, such as organizational and user-related barriers and operational barriers, which are also critical for blockchain to work in the Supply

Chain (Gonczol *et al.*, 2020; Wang; Han; Beynon-Davies, 2019). The function of humans in the adoption of blockchain is closely correlated with organizational and user-related barriers.

While human resistance may not be a technical issue, it should be given equal importance to the technology barriers discussed in this paper. People are crucial in overcoming technological barriers, as the decision-making process is carried out by individuals who represent the organization. Lokuge *et al.* (2019) assert that the implementation of innovations is influenced not only by the modernity of technology but also by the involvement of IT decision-makers and the existing organizational culture.

4.4.1 The technological barriers in each step of blockchain adoption process

Blockchain faces several technical challenges (Zheng *et al.*, 2018). No company can be fully decentralized without facing security, performance, and scalability issues (Iftekhar *et al.*, 2020). In this study, barriers are considered issues directly related to the use of blockchain that can prevent its commercial use (Kouhizadeh; Saberi; Sarkis, 2021).

Regarding RQ_1, 16 barriers were identified. Each barrier received a code "TB" (technological barrier), ranging from TB_1 to TB_{16}. Table 4.3 presents such barriers, their definitions, the number of papers dealing with these barriers, and the references.

Table 4.3 - Technological barriers for blockchain adoption in SCM

Barrier	Definition	References	Papers quantity
Fork Problems (TB1)	Forks can occur due to protocol or control code changes, requiring consensus among all nodes (Alam Khan *et al.*, 2020). Failure to reach consensus leads to a bifurcation, where upgraded and non-upgraded nodes coexist, resulting in parallel blocks (Pirrong, 2019).	(Alam Khan *et al.*, 2020; Andoni *et al.*, 2019; Babich; Hilary, 2020; Frizzo-Barker *et al.*, 2020; Mendling *et al.*, 2018; Pirrong, 2019; Upadhyay, 2020; Who; Team, *[S.d.]*; Yli-Huumo *et al.*, 2016; Ziolkowski; Miscione; Schwabe, 2020).	11
Lack of Interoperability and Standardization (TB2)	Challenges in sharing information across diverse blockchain systems due to the absence of universal standards, leading to fragmentation and complexity (Behnke; Janssen, 2020; Chang; Iakovou; Shi, 2020; Iftekhar *et al.*, 2020; Yadav *et al.*, 2020).	(Ahl *et al.*, 2020; Al-Jaroodi; Mohamed, 2019; Allen *et al.*, 2019; Andoni *et al.*, 2019; Azaria *et al.*, 2016; Babich; Hilary, 2020; Bai; Sarkis, 2020; Behnke; Janssen, 2020; Bodkhe *et al.*, 2020; Casino *et al.*, 2020; Chang; Iakovou; Shi, 2020; Chen *et al.*, 2020; Drljevic; Aranda; Stantchev, 2020; Feng *et al.*, 2020; Fosso Wamba *et al.*, 2020; Ghode *et al.*, 2020b; Gonczol *et al.*, 2020; Hackius; Petersen, 2020; Hughes *et al.*, 2019; Iftekhar *et al.*, 2020; Jahan; Khan, 2018; Justinia, 2019; Kouhizadeh; Zhu; Sarkis, 2020; Kurpjuweit *et al.*, 2021; Lacity, 2018; Liu *et al.*, 2019; Mattke *et al.*, 2019; Mazzei *et al.*, 2020; McGhin *et al.*, 2019; Meng *et al.*, 2018; Morkunas; Paschen; Boon, 2019; Olsen; Tomlin, 2020; Padmavathi; Rajagopalan, 2019; Pólvora *et al.*, 2020; Pournader *et al.*, 2020; Prasad *et al.*, 2018; Sukheja *et al.*, 2019; Tezel *et al.*, 2020; Van Hoek, 2019, 2020a; Vilkov; Tian, 2019; Wang *et al.*, 2019; Who; Team, *[S.d.]*; Wong *et al.*, 2020b; Yadav *et al.*, 2020; Yang, 2019; Zamani; Giaglis, 2018).	47
Privacy Problems (TB3)	Reluctance to share confidential information and risks of de-anonymization and transaction pattern exposure necessitates robust protection (Feng *et al.*, 2019; Galvez; Mejuto; Simal-Gandara, 2018; Wang *et al.*, 2019).	(Al-Jaroodi; Mohamed, 2019; Andoni *et al.*, 2019; Babich; Hilary, 2020; Behnke; Janssen, 2020; Biswas; Gupta, 2019; Chen *et al.*, 2020; Clohessy; Acton, 2019; Drljevic; Aranda; Stantchev, 2020; Feng *et al.*, 2020, 2019; Fosso Wamba *et al.*, 2020; Fu; Zhu, 2019; Ghode *et al.*, 2020b; Gonczol *et al.*, 2020; Huang *et al.*, 2019; Hughes *et al.*, 2019; Hussien *et al.*, 2019; Jiang *et al.*, 2019; Justinia, 2019; Kamble; Gunasekaran; Arha, 2019; Kamilaris; Fonts; Prenafeta-Boldú, 2019; Khezr *et al.*, 2019; Klöckner *et al.*, 2020; Kodym; Kubáč; Kavka, 2020; Kosba *et al.*, 2016; Kumar; Liu; Shan, 2020; Kurpjuweit *et al.*, 2021; Li *et al.*, 2021; Liu; Sun; Huang, 2020; Mackey *et al.*, 2019; Mattke *et al.*, 2019; McGhin *et al.*, 2019; Meng *et al.*, 2018; Meyer; Kuhn; Hartmann, 2019; Montecchi; Plangger; Etter, 2019; Padmavathi; Rajagopalan, 2019; Pólvora *et al.*, 2020; Prasad *et al.*, 2018; Rane; Narvel, 2019; Roehrs; Da Costa; Da Rosa Righi, 2017; Salman *et al.*, 2019; Schmidt; Wagner, 2019; Sheel; Nath, 2020; Srivastava *et al.*, 2019; Sternberg; Hofmann; Roeck, 2021; Sukheja *et al.*, 2019; Tandon *et al.*, 2020; Tezel *et al.*, 2020; Tiscini *et al.*, 2020; Upadhyay, 2020; Van Hoek, 2019, 2020a; Vilkov; Tian, 2019; Wang *et al.*, 2019; Wong *et al.*, 2020b, 2020a; Xu *et al.*, 2017, 2020; Yadav *et al.*, 2020; Yoo; Won, 2018; Zheng; Zhu; Si, 2019; Zheng *et al.*, 2018).	62

Barrier	Definition	References	Papers quantity
Lack of Reliability in Input Data (TB4)	Challenges in ensuring the reliability of data entered into blockchain, as blockchain can verify data accuracy but not its quality (Howson, 2020; Lu *et al.*, 2019; Schmidt; Wagner, 2019).	(Allen *et al.*, 2019; Babich; Hilary, 2020; Boukis, 2020; Chen *et al.*, 2020; Ching-Fu, 2019; Galvez; Mejuto; Simal-Gandara, 2018; Howson, 2020; Kamble; Gunasekaran; Sharma, 2020; Khezr *et al.*, 2019; Lu *et al.*, 2019; Olsen; Tomlin, 2020; Rogerson; Parry, 2020; Schmidt; Wagner, 2019; Tezel *et al.*, 2020; Van Hoek, 2019, 2020a; Wang *et al.*, 2019; Wong *et al.*, 2020a; Ziolkowski; Miscione; Schwabe, 2020).	19
Immutability (TB5)	Recorded data cannot be altered, which can limit adaptability and pose challenges in cases of disputed transactions or data entry errors (Ghode *et al.*, 2020a; Hofmann *et al.*, 2017; Lo *et al.*, 2018).	(Behnke; Janssen, 2020; Biswas; Gupta, 2019; Chen *et al.*, 2020; Clohessy; Acton, 2019; Farooque *et al.*, 2020; Ghode *et al.*, 2020a, 2020b; Hackius; Petersen, 2020; Hughes *et al.*, 2019; Kouhizadeh; Saberi; Sarkis, 2021; Mariappan, 2019; Padmavathi; Rajagopalan, 2019; Pólvora *et al.*, 2020; Pournader *et al.*, 2020; Saberi *et al.*, 2019; Tiscini *et al.*, 2020; Upadhyay, 2020; Yoo; Won, 2018; Ziolkowski; Miscione; Schwabe, 2020).	19
Black-box Effect (TB6)	Users must trust the process's integrity, even without technical knowledge. Trust extends to specific implementations involving third parties not part of the SC (Babich; Hilary, 2020).	(Babich; Hilary, 2019, 2020; Fosso Wamba *et al.*, 2020; Sternberg; Hofmann; Roeck, 2021).	4
Security Problems (TB7)	Vulnerabilities to hacker attacks, 51 percent attack, key stolen/lost, inaccurate information spread, and access to confidential data, exacerbated by blockchain's operation across multiple platforms (Al-Jaroodi; Mohamed, 2019; Kouhizadeh; Saberi; Sarkis, 2021).	(Ahl *et al.*, 2020; Alam Khan *et al.*, 2020; Al-Jaroodi; Mohamed, 2019; Behnke; Janssen, 2020; Biswas; Gupta, 2019; Boukis, 2020; Ching-Fu, 2019; Clohessy; Acton, 2019; Drljevic; Aranda; Stantchev, 2020; Farooque *et al.*, 2020; Frizzo-Barker *et al.*, 2020; Fu; Zhu, 2019; Huang *et al.*, 2019; Hughes *et al.*, 2019; Hussien *et al.*, 2019; Jahan; Khan, 2018; Kamble; Gunasekaran; Sharma, 2020; Kamilaris; Fonts; Prenafeta-Boldú, 2019; Khezr *et al.*, 2019; Kim, 2020; Kodym; Kubáč; Kavka, 2020; Kouhizadeh; Saberi; Sarkis, 2021; Kouhizadeh; Zhu; Sarkis, 2020; Kuo; Kim; Ohno-Machado, 2017; Kurpjuweit *et al.*, 2021; Lee; Azamfar; Singh, 2019; Lin *et al.*, 2019, 2017; Lu *et al.*, 2019; Mackey *et al.*, 2019; Makridakis, 2019; Matsuo, 2017; Mazzei *et al.*, 2020; McGhin *et al.*, 2019; Mendling *et al.*, 2018; Padmavathi; Rajagopalan, 2019; Pólvora *et al.*, 2020; Prasad *et al.*, 2018; Prashar *et al.*, 2020; Roehrs; Da Costa; Da Rosa Righi, 2017; Saberi *et al.*, 2019; Saberi; Kouhizadeh; Sarkis, 2019; Srivastava *et al.*, 2019; Sukheja *et al.*, 2019; Tandon *et al.*, 2020; Tiscini *et al.*, 2020; Upadhyay, 2020; Van Hoek, 2019, 2020a; Vilkov; Tian, 2019; Viriyasitavat; Anuphaptrirong; Hoonsopon, 2019; WANG *et al.*, 2017; Wang *et al.*, 2019; White, 2017; Who; Team, *[S.d.]*; Wong *et al.*, 2020b; Yang *et al.*, 2020; Yli-Huumo *et al.*, 2016; Zhang *et al.*, 2018; Zheng; Zhu; Si, 2019).	60
High Latency (TB8)	Higher response time per transaction in blockchain compared to traditional systems, influenced by factors like network delays and transaction rates (Kuzlu *et al.*, 2019; Yasaweerasinghelage; Staples; Weber, 2017; Yli-Huumo *et al.*, 2016).	(Ahl *et al.*, 2020; Alam Khan *et al.*, 2020; Alrubei *et al.*, 2020; Andoni *et al.*, 2019; Bodkhe *et al.*, 2020; Croman *et al.*, 2016; Feng *et al.*, 2020; Fosso Wamba *et al.*, 2020; Frizzo-Barker *et al.*, 2020; Gonczol *et al.*, 2020; Hughes *et al.*, 2019; Hussien *et al.*, 2019; Jamil *et al.*, 2019; Lin *et al.*, 2017; Mao *et al.*, 2019; Mendling *et al.*, 2018; Meng *et al.*, 2018; Meyer; Kuhn; Hartmann, 2019; Morkunas; Paschen; Boon, 2019; Padmavathi; Rajagopalan, 2019; Panarello *et al.*, 2018; Pournader *et al.*, 2020; Prasad *et al.*, 2018; Prashar *et al.*, 2020; Salman *et al.*, 2019; Seok; Park; Park, 2019; Tandon *et al.*, 2020; Tiscini *et al.*, 2020; WANG *et al.*, 2017;	36

Barrier	Definition	References	Papers quantity
		Xu *et al.*, 2017; Yli-Huumo *et al.*, 2016; Younan *et al.*, 2020; Zhao *et al.*, 2019; Zheng; Zhu; Si, 2019)	
Scalability Problems (TB9)	Limited storage capacity and transaction processing capabilities strain blockchain's capacity as transaction volume and user data increase (Azzi; Chamoun; Sokhn, 2019; Biswas; Gupta, 2019; Kouhizadeh; Saberi; Sarkis, 2021a; Kuzlu *et al.*, 2019).	(Al-Jaroodi; Mohamed, 2019; Alrubei *et al.*, 2020; Andoni *et al.*, 2019; Behnke; Janssen, 2020; Biswas; Gupta, 2019; Bodkhe *et al.*, 2020; Casino *et al.*, 2020; Chang; Iakovou; Shi, 2020; Chen *et al.*, 2020; Ching-Fu, 2019; Croman *et al.*, 2016; Drljevic; Aranda; Stantchev, 2020; Fosso Wamba *et al.*, 2020; Frizzo-Barker *et al.*, 2020; Hald; Kinra, 2019; Hang; Choi; Kim, 2019; Hughes *et al.*, 2019; Hussien *et al.*, 2019; Jahan; Khan, 2018; Jawaji *et al.*, 2020; Jiang *et al.*, 2019; Justinia, 2019; Kim, 2020; Kouhizadeh; Sarkis; Zhu, 2019; Kuo; Kim; Ohno-Machado, 2017; Kurpjuweit *et al.*, 2021; Lacity, 2018; Lin *et al.*, 2017; Makridakis, 2019; Mao *et al.*, 2019; Mazlan *et al.*, 2020; Mazzei *et al.*, 2020; McGhin *et al.*, 2019; Meyer; Kuhn; Hartmann, 2019; Min, 2019; Otte; De Vos; Pouwelse, 2020; Padmavathi; Rajagopalan, 2019; Panarello *et al.*, 2018; Prasad *et al.*, 2018; Rane; Narvel, 2019; Salman *et al.*, 2019; Sanka; Cheung, 2019; Seok; Park; Park, 2019; Shojaei; Wang; Fenner, 2020; Sukheja *et al.*, 2019; T, 2020; Tan *et al.*, 2020; Tandon *et al.*, 2020; Tezel *et al.*, 2020; Tiscini *et al.*, 2020; Upadhyay, 2020; Van Hoek, 2019, 2020a; Vatankhah Barenji *et al.*, 2020; Vinay Reddy, 2019; Viriyasitavat; Anuphaptrirong; Hoonsopon, 2019; Who; Team, *[S.d.]*; Xu *et al.*, 2017; Yadav *et al.*, 2020; Yang, 2019; Yang *et al.*, 2020; Yli-Huumo *et al.*, 2016; Younan *et al.*, 2020; Yu; Liang; Xu, 2019; Zhang *et al.*, 2018; Zhao *et al.*, 2019; Zheng; Zhu; Si, 2019; Zheng *et al.*, 2018).	68
Need for High Computational Speed/Processing Power (TB10)	PoW consensus algorithms require substantial computational resources, exceeding the capabilities of many IoT devices and raising sustainability concerns (Seok; Park; Park, 2019).	(Bodkhe *et al.*, 2020; Fosso Wamba *et al.*, 2020; Grigoreva; Garifova; Polovkina, 2019; Hussien *et al.*, 2019; Kamble; Gunasekaran; Sharma, 2020; Mundra, 2018; Salman *et al.*, 2019; Seok; Park; Park, 2019; Shojaei; Wang; Fenner, 2020; Van Hoek, 2019, 2020a; White, 2017; Yadav *et al.*, 2020).	13
Lack of Tools for blockchain Implementation (TB11)	Absence of standardized solutions for product tagging complicates the integration of physical and digital worlds (Kouhizadeh; Saberi; Sarkis, 2021; Kurpjuweit *et al.*, 2021).	(Farooque *et al.*, 2020; Gonczol *et al.*, 2020; Kouhizadeh; Saberi; Sarkis, 2021; Kurpjuweit *et al.*, 2021; Saberi; Kouhizadeh; Sarkis, 2019).	5
Usability Problems (TB12)	Complexity of blockchain's underlying structure and cryptography principles poses challenges for average users, hindering technology adoption (Wong *et al.*, 2020b; Zamani; Giaglis, 2018).	(Alam Khan *et al.*, 2020; Frizzo-Barker *et al.*, 2020; Hackius; Petersen, 2020; Mendling *et al.*, 2018; Wang *et al.*, 2019; Wong *et al.*, 2020b; Yli-Huumo *et al.*, 2016; Zamani; Giaglis, 2018).	8
Underperforming Functionality (TB13)	Blockchain networks often exhibit inefficiencies by design, with high energy and bandwidth requirements, leading to lower performance compared to centralized databases (Babich; Hilary, 2020).	(Babich; Hilary, 2020; Rane; Narvel, 2019).	2

Barrier	Definition	References	Papers quantity
Complexity in System Design (TB14)	The architecture, structure, and implementation of blockchain-based systems are complex, which hinders their understanding and implementation (Lakshmi; Sricharan, 2019).	(Bodkhe *et al.*, 2020; Clohessy; Acton, 2019; Fosso Wamba *et al.*, 2020; Hackius; Petersen, 2020; Lakshmi; Sricharan, 2019; Meng *et al.*, 2018; Pereira; Tavalaei; Ozalp, 2019; Perez *et al.*, 2020; Rane; Narvel, 2019; Upadhyay, 2020; Vilkov; Tian, 2019; Yadav *et al.*, 2020; Zheng; Zhu; Si, 2019).	13
Increased IT Handling Complexity (TB15)	The growing complexity of blockchain and the need for new IT routines to manage additional interfaces contribute to increased IT handling complexity, necessitating a workforce with enhanced technical expertise and additional resources dedicated to managing and sustaining the current infrastructure (Kamilaris; Fonts; Prenafeta-Boldύ, 2019; Sternberg; Hofmann; Roeck, 2021).	(Huang *et al.*, 2019; Kamilaris; Fonts; Prenafeta-Boldύ, 2019; Sternberg; Hofmann; Roeck, 2021; Van Hoek, 2019, 2020a; Wang *et al.*, 2019).	6
Smart Contract Problems (TB16)	Operational challenges in smart contracts, including limitations in execution, integration within existing systems, inflexibility and errors in coding smart contracts (Fitzhan *et al.*, 2020; Kumar; Liu; Shan, 2020; Tezel *et al.*, 2020).	(Cole; Stevenson; Aitken, 2019; Feng *et al.*, 2020; Fitzhan *et al.*, 2020; Hald; Kinra, 2019; Kumar; Liu; Shan, 2020; Tezel *et al.*, 2020; Younan *et al.*, 2020).	7

Source: Author's own work.

Although all the barriers mentioned in Table 4.3 are considered technological issues, most of them are related to humans. These barriers can generate a certain reluctance to adopt blockchain, as they have profound implications on human perceptions. Overcoming these technological barriers entails not only technical solutions, but also approaches that seek acceptance, trust, and human adaptation to the technology.

The *fork problems* barrier can cause resistance in human acceptability as a result of uncertainties regarding the stability and security of the system. The risk of incompatibility with other systems is a result of the *lack of interoperability and standardization* barrier, which generates uncertainty. In sectors where confidentiality is essential, decision-makers may exhibit resistance to *privacy issues*. When irreversible human error is a concern, *immutability* can be perceived as an impediment. The *black-box effect* can lead to reluctance among users due to a lack of comprehension of the fundamentals of blockchain 's operation, which can incite skepticism.

Hacks and vulnerabilities are significant *security concerns* that have the potential to erode the trust of users and organizations in blockchain. The *lack of tools for blockchain implementation* can serve as a deterrent to developers and organizations. Due to *usability problems*, users may find it challenging to interact with blockchain applications in a manner that is both intuitive and efficient.

Specialized skills and additional resources may be necessary due to the *increased complexity of IT handling*. The upskilling and technical training or hiring of staff is certainly a huge and important step in any implementation of such importance. The deployment of blockchain means that an organization needs profound modification of its processes, information systems, and routines, and hence represents a major effort in change management. The blockchain protocol level is distinguished by iterative exchanges between human agents and the blockchain protocol, resulting in a strong interconnection between the technical and human aspects that cannot be separated (Rossi *et al.*, 2019).

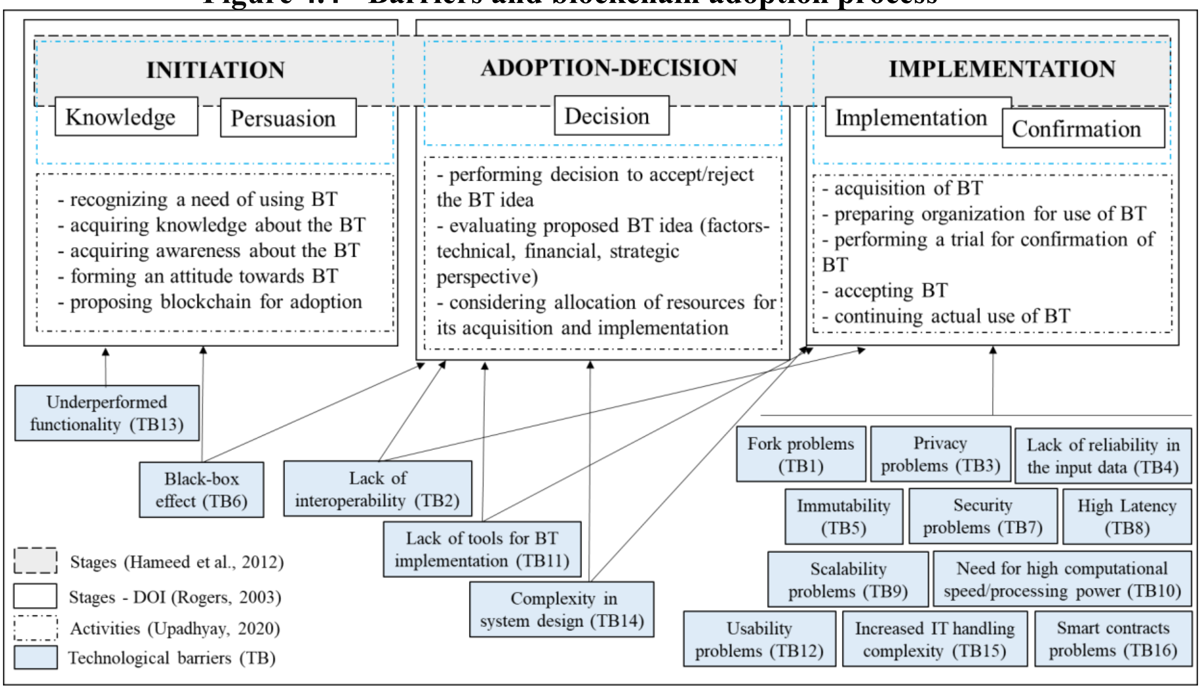
The majority of these barriers are associated with the individual who is crucial in the acceptance and decision to adopt blockchain. This relationship refers to characteristics such as human resistance, skepticism, reluctance, and lack of trust when confronted with barriers that challenge the organization's or the individual's capacity to surmount them. Hence, it is imperative to acknowledge that the technical and human dimensions are interconnected and indivisible. To ensure that blockchain has a tangible effect in the real world, it is crucial to comprehend the social and behavioral factors and difficulties associated with deploying blockchain systems, as explored in the works of Schmidt and Wagner (2019) and Köhler and Pizzol (2020).

Our examination of technological barriers prompted a discussion on the context of blockchain adoption, aiming to correlate these barriers with the innovation adoption process. Additional research underscores the necessity for deeper exploration into organizational dynamics and decision-making regarding blockchain adoption (Frizzo-Barker *et al.*, 2020; Upadhyay, 2020).

Adopting a new idea is challenging, even with obvious advantages (Rogers, 2003). Several studies proposed investigating the organizational innovation adoption process (Frambach; Schillewaert, 2002; Hameed; Counsell; Swift, 2012; Jöhnk; Weißert; Wyrtki, 2021). Wamba and Queiroz (2020) comment on the need for more efforts to understand the stages of the blockchain adoption process.

In our research, we identify a relationship between the 16 identified barriers and their emergence across various stages of the blockchain adoption process (Figure 4.4). This mapping highlights potential points where organizations might encounter obstacles or consider rejecting blockchain. By presenting this theoretical model, we aim to equip organizations with a comprehensive understanding of how blockchain operates. This understanding will enable them to anticipate and effectively navigate the interplay between these barriers and the adoption process.

Figure 4.4 - Barriers and blockchain adoption process



Source: Author's own work.

During the *initiation stage*, companies acknowledge the necessity of blockchain, gain knowledge, form an attitude, and consider adopting blockchain (Upadhyay, 2020). This stage encompasses the *black-box effect* and *underperforming functionality* barriers. The *black-box effect* in blockchain allows for easy observation of system inputs and outputs, yet decision-makers may hesitate to adopt it due to challenges in comprehending and visualizing the blockchain operating process. This theoretical analysis was done (and described in Table 4.4) for each technological barrier and adoption stage, which resulted in the allocation of barriers presented in our framework.

At the *adoption-decision stage*, companies decide to accept/reject the blockchain idea, evaluate the technical factors and the financial and strategic perspective, and consider allocating resources for its acquisition and implementation (Upadhyay, 2020). This stage includes the *black-box effect* (also present in the initiation stage), *lack of interoperability and standardization, lack of tools for blockchain implementation,* and *complexity in system design* barriers.

In the *implementation stage*, organizations prepare for the acquisition and use of blockchain, perform a trial for confirmation, and accept and continue its current use (Upadhyay, 2020). This stage includes *lack of interoperability and standardization, lack of tools for* blockchain *implementation,* and *complexity in system design* barriers (also present in the adoption-decision stage), *fork problems, privacy problems, lack of reliability in input data, immutability, security problems, high latency, scalability problems, need for high computational speed/processing power, usability problems, increased IT handling complexity* and *smart contract problems*.

Table 4.4 - Allocation of barriers in blockchain adoption stages

Barriers	Initiation Stage	Adoption-decision Stage	Implementation Stage
Fork Problems (TB1)	-	-	Updates to the protocols will be required once the technology is already in use.
Lack of Interoperability and Standardization (TB2)	-	At this stage, the necessary resources for the implementation of BT are analyzed, and the non-possibility of communication (interoperability) for the transition between centralized systems and BT can interfere with the decision to adopt the technology.	The lack of interoperability will interfere with the process of implementing and using BT, hindering cooperation with partners in the supply chain.
Privacy Problems (TB3)	-	-	There may be problems and hesitation in sharing information while using BT.
Lack of Reliability in Input Data (TB4)	-	-	The lack of reliability in the input data is a reality that will be faced during the use of BT, after its implementation.
Immutability (TB5)	-	-	The immutability of data can be a problem while BT is in use, due to the lack of flexibility to correct errors and to delete information.

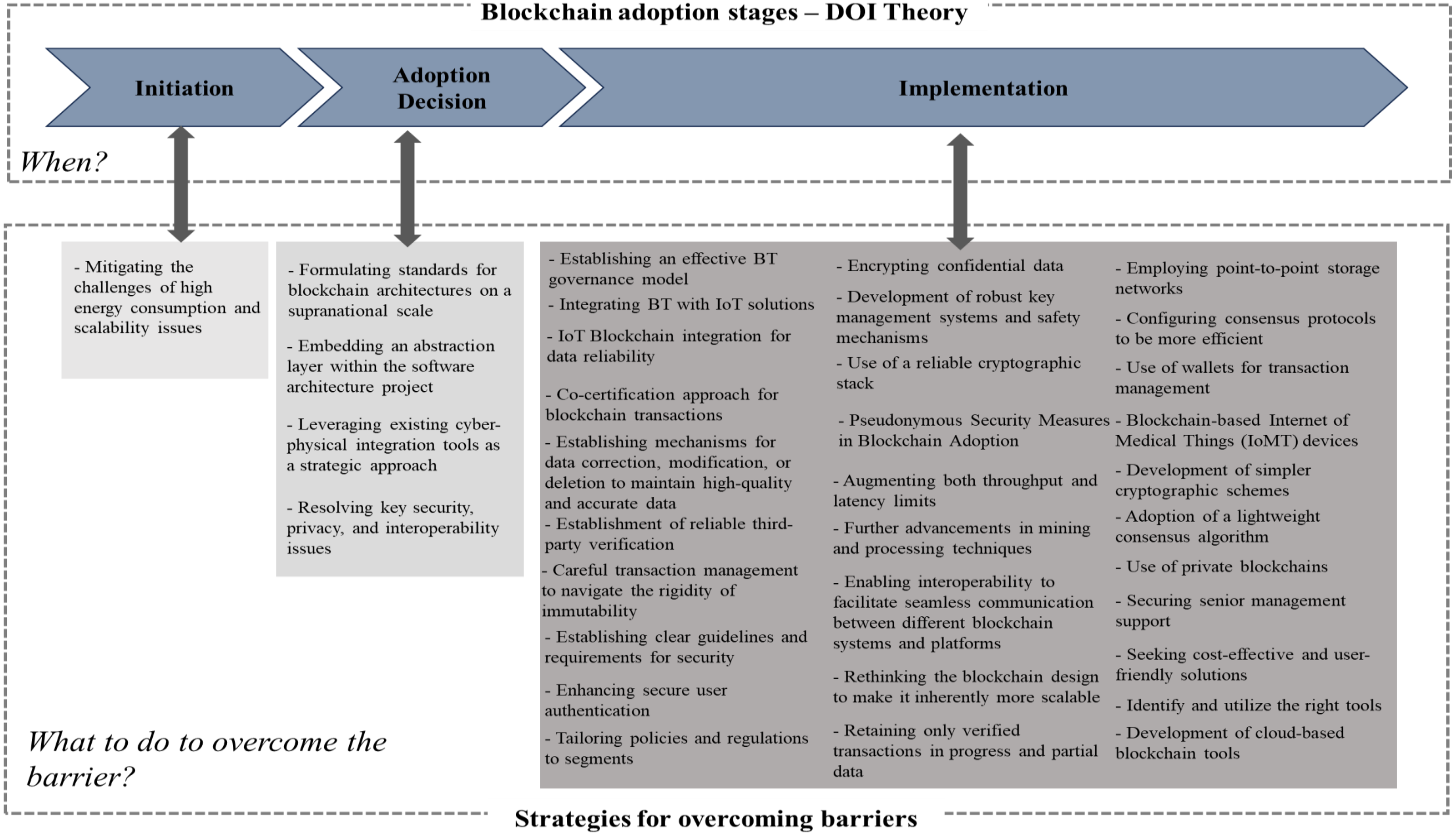
Barriers	Initiation Stage	Adoption-decision Stage	Implementation Stage
Black-box Effect (TB6)	Decision-makers may hesitate to proceed with the adoption due to the difficulty of understanding and visualizing the BT operating process.	Even if in the initiation stage the decision-maker starts to trust the integrity of a decentralized system, the lack of understanding of its technical fundamentals may get in the way of drawing up a plan for allocating the resources needed for the implementation of BT, at the adoption-decision stage.	-
Security Problems (TB7)	-	-	Security issues such as vulnerability to hacker attacks will be faced when BT is already in use, after its implementation.
High Latency (TB8)	-	-	Latency issues will be faced while BT is in use, i.e. after its implementation.
Scalability Problems (TB9)	-	-	Scalability issues will also be faced while BT is in use, i.e. after its implementation.
Need for High Computational Speed/Processing Power (TB10)	-	-	The intensive computational consumption will represent a problem when BT is already implemented, resulting in high sustainability costs.
Lack of Tools for BT Implementation (TB11)	-	At this stage, the necessary infrastructure for the adoption of BT is analyzed, the lack of tools for the implementation can be an impediment to the adoption decision.	The lack of tools will compromise the effective BT implementation process.
Usability Problems (TB12)	-	-	Difficulties related to BT usability will affect organizations after implementing the technology.
Underperforming Functionality (TB13)	Decision-makers may notice that the centralized database that the organization uses is more efficient than BT, not recognizing advantages in its substitution, thus declining the decision to adopt.	-	-
Complexity in System Design (TB14)	-	Such complexity may imply the need for many resources that the company may not have available, which may hinder adoption at this stage.	Although the responsibility for developing the system is largely the responsibility of the technology provider company, a joint effort will be required to prepare the organization for testing and using BT, activities that can be affected by the complexity of developing these systems.
Increased IT Handling Complexity (TB15)	-	-	The use of BT will represent a major change in business models that use centralized systems, inserting new routines and increasing the complexity of dealing with information technology.
Smart Contract Problems (TB16)	-	-	Coding of smart contracts will be required while using BT, to regulate trading between companies, so issues related to this barrier will arise at this stage.

Source: Author’s own work.

4.4.2 Framework for Overcoming Technological Barriers in Blockchain Adoption: A Phased Approach

Our study systematically investigates the technological barriers to blockchain adoption within Supply Chain Management and outlines strategies to overcome these hurdles. This dual focus allows us to contribute to the existing body of knowledge and offer actionable insights for practitioners in the field. Figure 4.5 presents a framework that summarizes all the strategies that need to be performed in each phase of the DOI model. Overall, the proposed framework underlines a strategic and phased approach to overcoming the technological barriers to blockchain adoption, suggesting that each stage of the DOI theory and Hameed, Counsell and Swift (2012) presents distinct challenges that can be addressed with targeted strategies to ensure successful integration of blockchain within Supply Chains.

Figure 4.5 - A framework for overcoming technological barriers in blockchain adoption



Source: Author's own work.

Our framework presents a comprehensive overview of the mitigation strategies for barriers to the adoption of blockchain across three key stages, Initiation, Adoption Decision, and Implementation, guided by the Diffusion of Innovations (DOI) theory.

4.4.2.1 Initiation Phase: Laying the Foundation for Blockchain Innovation

The challenge of the *black-box effect* (TB_6) underscores a significant barrier in the blockchain domain where the complexity and opacity of the technology can hinder its understanding and acceptance. While specific strategies to address this barrier directly were not identified in the literature, overcoming it is crucial for enhancing the entire SC. Addressing the *black-box effect* involves demystifying the technology to increase awareness, acceptance, and adoption among Supply Chain members, as emphasized by Meng *et al.* (2018). By making the workings of blockchain more transparent and comprehensible, stakeholders are more likely to trust and adopt it, thereby facilitating a broader acceptance across the Supply Chain network.

Addressing the issue of *underperforming functionality* (TB_{13}) is crucial for enhancing the efficacy of blockchain within Supply Chains. A key strategy to overcome this barrier, as outlined by Babich and Hilary (2019), involves **mitigating the challenges of high energy consumption and scalability issues** that are often associated with blockchain. By tackling these problems, blockchain systems can become more efficient and sustainable, making them more competitive and appealing than traditional systems. Overcoming the underperforming functionality of blockchain leads to a significant improvement across the entire SC, notably increasing blockchain adherence, as highlighted by Babich and Hilary (2019).

During the Initiation stage, the focus is on mitigating the high energy consumption and scalability issues inherent in blockchain. It is crucial to take these actions to overcome the barriers that emerge during the initial phase.

We might consider improving energy efficiency to be a useful kind of persuasion since, in addition to decreasing environmental consequences, it may also reduce operational costs for companies, particularly in areas where cost efficiency is critical to competitiveness. Furthermore, blockchain's scalability may enhance adoption among stakeholders who handle a large volume of transactions. Scalability is critical for ensuring the successful functioning of blockchain in applications involving Supply Chains, where many organizations interact and exchange information. Solving barriers like high energy consumption and scalability issues may assist businesses develop a more positive attitude toward blockchain implementation.

4.4.2.2 Adoption Decision Phase: Evaluating and Committing to Blockchain

A holistic strategy is paramount to tackle the significant barrier of *lack of interoperability and standardization* (TB_2) in blockchain implementation. The literature posits a dual approach to surmount this obstacle: initially, by **formulating standards for blockchain architectures on a supranational scale**, as advocated by Andoni *et al.* (2019), Allen *et al.* (2019), Yang (2019), Behnke and Janssen (2020), Feng *et al.* (2020), Pólvora *et al.* (2020), Iftekhar *et al.* (2020), and Chen *et al.* (2020); and subsequently, by **embedding an abstraction layer within the software architecture project**, a method discussed by Mazzei *et al.* (2020). Implementing this strategy necessitates a series of concerted actions.

As Zamani and Giaglis (2018) and Pólvora *et al.* (2020) suggested, establishing consortia and alliances among companies lays the foundational groundwork. This strategy is implemented in Blockchain Interoperability Alliance that was founded in a joint effort by companies such as Aion, ICO, Wanchain, and others, to improve communication between these systems (Drljevic; Aranda; Stantchev, 2020). These efforts reiterate the need for collaboration from all stakeholders to achieve full interoperability (Feng *et al.*, 2020).

This effort is augmented by middleware integration to facilitate system integration, as recommended by Prasad *et al.* (2018) and Fosso Wamba, Queiroz and Trinchera (2020). This strategy was put into practice in Origin Trail, which implemented an agnostic middleware that provides interoperability between blockchains (Fosso Wamba *et al.*, 2020). Middleware can also promote the integration of blockchain with data management systems used in SC&L, such as ERP, Warehouse Management Systems (WMS), Customer Relationship Management (CRM), and Supplier Relationship Management (SRM) (Pournader *et al.*, 2020). Finlync (a privately held global fintech company) developed an agnostic middleware to enable SAP integration for Ethereum and Hyperledger (Prasad *et al.*, 2018).

The formation of a technical committee, as endorsed by Yang (2019) and Allen *et al.* (2019), bolsters the structural framework for standardization. A technical committee of the International Standardization Organization (ISO/TC307) was established to promote the design of technical blockchain standards (Allen *et al.*, 2019; Eyers, 2018; ISO, 2017; Yang, 2019).

Further, the utilization of blockchain-based systems tailored to resolve interoperability issues in healthcare, as demonstrated by McGhin *et al.* (2019), along with blockchain network projects designed to foster interoperable systems, as evidenced by Mattke *et al.* (2019), Pólvora *et al.* (2020), and Chang, Iakovou and Shi (2020), is critical. Examples of this strategy employed in this industry include OmniPHR (Roehrs; Da Costa; Da Rosa Righi, 2017), Medrec (Azaria *et al.*, 2016), Secure System for Pervasive Social Network (PSN) (Zhang; Xue; Huang, 2016), and Fast Healthcare Resources (FHIRChain) (Zhang *et al.*, 2018). The Drug Supply Chain Security Act (DSCSA) has called for an interoperable electronic system to be developed, from which it will be possible to track drugs automatically in the Supply Chain (Mattke *et al.*, 2019).

The Cosmos Network and The Polkadot Network are projects for creating a blockchain network (Chang; Iakovou; Shi, 2020). These technologies propose validators as bridges between different blockchain environments, such as Oraclize (Chang; Iakovou; Shi, 2020). Moog is developing VeriPart, a blockchain-based service, and has partnered with Nuco, which is building an interoperable blockchain network called Aion (Lacity, 2018). Moog is also working with a significant supplier so that the platform can also connect to legacy ERP systems (Lacity, 2018).

The incorporation of open-source solutions, as recommended by Hughes *et al.* (2019), also plays a vital role. Organizations are studying the feasibility of approaches using Hyperledger (an *open-source solution* hosted by the Linux Foundation) and Tendermint (a general-purpose blockchain consensus engine able to host arbitrary application states) (Hughes *et al.*, 2019).

Overcoming the *interoperability and standardization* barrier heralds significant enhancements across the SC. It enables data aggregation, permitting synergistic use of information among participants, an improvement emphasized by Babich and Hilary (2020). It also assures compatibility among diverse blockchain systems, as noted by Chang, Iakovou and Shi (2020) and Bourlakis and Seuring (2022), and between blockchains and the prevailing data management systems in SC&L, facilitating real-time information sharing among stakeholders, a crucial development highlighted by Pournader *et al.* (2020).

The challenge of a *lack of tools for blockchain implementation* (TB_{11}) necessitates innovative solutions to bridge the gap between the physical and digital realms within

Supply Chains. The literature suggests **leveraging existing cyber-physical integration tools as a strategic approach** to address this barrier, as discussed by Kurpjuweit *et al.* (2021) and Gonczol *et al.* (2020). The use of paired Radio Frequency Identification (RFID) tags, as recommended by the same authors, offers a tangible solution by providing a seamless link between physical items and their digital counterparts on the blockchain. Additionally, incorporating Nearfield Communication (NFC) technology or barcodes, as suggested by Kurpjuweit *et al.* (2021), further enhances the connection between the physical and digital worlds, facilitating the tracking and authentication of assets throughout the SC.

More information about RFID can be found in Stockman (1948), the combination of RFID and blockchain in Tian (2016) and Vilkov and Tian (2019), and the combination of blockchain and NFC in Alzahrani and Bulusu (2018). These technologies enable the creation of natively digital assets, significantly reducing data unreliability and enhancing the integrity of input data, a crucial improvement highlighted by Babich and Hilary (2020).

The challenge of *complexity in system design* (TB_{14}) is a significant barrier to the effective deployment of blockchain in Supply Chains. Addressing this barrier necessitates a focus on **resolving key security, privacy, and interoperability issues**, as identified by Yadav *et al.* (2020). These elements are critical to ensuring that blockchain systems are robust, user-friendly, and capable of seamless integration within diverse Supply Chain environments. Overcoming the complexity in blockchain system design benefits the entire Supply Chain and is particularly advantageous for technology providers and developers. By simplifying the design and enhancing the functionality of blockchain systems, the migration from traditional centralized systems to more decentralized blockchain -based systems becomes more feasible and attractive, as highlighted by Clohessy and Acton (2019). This transition facilitates a more agile, transparent, and secure Supply Chain Management process.

In concluding our discussion on the adoption decision phase, it's imperative to highlight the emergence of the *black box effect* (TB_6). The presence of this barrier underscores a significant challenge that must be addressed to improve the prospects of successful blockchain implementation. As previously noted, our SLR did not uncover any strategies specifically tailored to directly mitigate this barrier, revealing a notable gap in current research. This absence of targeted solutions for the "black box effect" presents a critical area for future investigation. Addressing this gap is essential for developing comprehensive strategies that enhance transparency and understanding of blockchain s, thereby facilitating their broader acceptance and integration.

As organizations transition to the Adoption Decision stage, strategies include formulating international standards for blockchain architecture, embedding abstraction layers within software projects, leveraging cyber-physical integration tools, and resolving key issues around security, privacy, and interoperability. At this stage, firms must decide whether or not to embrace blockchain based on solid information about the alignment of blockchain with their strategic objectives, evaluating the cost-benefit ratio of implementation, and comparing blockchain to other available options.

Developing international standards for blockchain architecture assists in reducing the uncertainty and concern of adopting a technology that is still gaining traction, such as blockchain. Furthermore, established standards can help blockchain integrate and interoperate with current systems within enterprises, as well as with different blockchain networks throughout the world. Embedding abstraction layers in software projects can help simplify the complexity of blockchain for both developers and end users. Leveraging cyber-physical integration tools can demonstrate how enterprises may benefit from blockchain, both in terms of process optimization and as a driver of digital transformation.

Resolving key issues such as security, privacy, and interoperability can reduce companies' hesitation to adopt a technology capable of increasing reliability and trust, particularly in environments such as the Supply Chain where there are conflicts of interest. In this context, companies are interested in data protection and regulatory compliance. Addressing all these challenges at this stage would undoubtedly offer the organization with stronger justifications for making a positive decision to use blockchain.

4.4.2.3 Implementation Phase: Executing Blockchain Integration

Addressing the challenge of *fork problems* (TB_1) requires a focused approach. The literature suggests **establishing an effective blockchain governance model** as a pivotal strategy to navigate this issue, as Pirrong (2019) and Ziolkowski, Miscione and Schwabe (2020) highlighted. Implementing such governance can significantly mitigate the risk of blockchain forks, where nodes may diverge into separate chains, thus avoiding bifurcation, a critical improvement underscored by Alam Khan *et al.* (2020) and Babich and Hilary (2020). Moreover, central governance fosters enhanced communication and compatibility across different blockchain versions, whether they are updated or adhere to non-updated protocol versions, as noted by Alam Khan *et al.* (2020) and Babich and Hilary (2020). Resolving fork-related problems facilitates superior integration and communication among Supply Chain business entities. This strategic approach directly addresses the *fork problems* (TB_1) and strengthens the overall blockchain infrastructure within the SC, ensuring a more cohesive and efficient operational framework.

Establishing an effective blockchain governance model can be achieved by formulating policies, guidelines, and organizational structures that regulate its usage and management (Zwitter; Hazenberg, 2020). Good governance in liberal democratic institutions typically involves strict adherence to the rule of law. This means that current laws and regulations are applied in a straightforward and unbiased manner, without being influenced by social or political factors (De Filippi; Mannan; Reijers, 2020).

Confronting *privacy issues* (TB_3), necessitates a nuanced and multifaceted strategy. The literature underscores the importance of **integrating Blockchain Technology (BT) with Internet of Things (IoT) solutions** as an effective approach to mitigating privacy concerns, as suggested by Justinia (2019). To operationalize this strategy, a series of targeted actions are proposed in the literature:

a) Employing decentralized machine learning to ensure minimal privacy infringement (Liu; Sun; Huang, 2020);
b) Adopting secure collaborative machine learning frameworks that incorporate differential privacy to safeguard sensitive data (Liu; Sun; Huang, 2020);
c) Establishing a distributed trusted communication network to enhance secure exchanges (Li *et al.*, 2021);
d) Developing a distributed and reliable cloud data source architecture that leverages blockchain and ProvChain for enhanced data integrity and privacy (Yoo; Won, 2018);
e) Utilizing Federated or Consortium Blockchains to control access and improve privacy (Padmavathi; Rajagopalan, 2019; Zheng; Zhu; Si, 2019);
f) Implementing key agreement protocols like Elliptic Curve Diffie-Hellman-Merkle (ECDHM) to secure communications (Sukheja *et al.*, 2019);
g) Introducing decentralized smart contract systems, such as Hawk, that preserve privacy while executing contracts (Fu; Zhu, 2019; Kosba *et al.*, 2016; Zhao *et al.*, 2019);

h) Creating access control models and data authority management methods to regulate data access and ownership (Huang *et al.*, 2019; Jiang *et al.*, 2019).;
i) Ensuring pseudonymity or employing permissioned ledgers to anonymize transactions (Andoni *et al.*, 2019);
j) Exploring solutions, prototypes, projects, and schemes specifically tailored for the healthcare sector to address its unique privacy requirements (McGhin *et al.*, 2019).

Efforts and techniques to address *privacy issues* include Stealth Addresses, Pedersen Commitments, Ring Signature, Homomorphic Encryption, Zero-Knowledge-Proof (Hamida *et al.*, 2017; Zhao *et al.*, 2019), encrypted transactions (Kosba *et al.*, 2016; Zhao *et al.*, 2019), double blockchain architecture perspective (Zhao *et al.*, 2019), Centralized and Decentralized mixing (Feng *et al.*, 2019; Zheng *et al.*, 2018), CryptoNote, and NIZK (Feng *et al.*, 2019).

Salman *et al.* (2019) mentioned Zyskind's approach, Blockchain-Based Data Sharing (BBDS), FairAccess, Dynamic Access Control for IoT Using FairAccess, Decentralized Runtime Access Monitoring System (DRAMS), and Data Privacy for IoT Data Storage and Sharing. Gonczol *et al.* (2020) highlighted Hyperledger Fabric and Permissioned Systems, the recording of off-chain data hashes, role-based access control, and Multi-Chain Architectures.

Jiang *et al.* (2019) proposed an access control model where members need to request access to data records. To protect the confidentiality, Huang *et al.* (2019) designed a data authority management method to regulate access to sensor data. When using pseudonymity or allowed ledgers, access to data can be restricted to authorized parties (Andoni *et al.*, 2019).

The healthcare sector presents solutions to improve, among other problems, privacy, with the literature highlighting: Health Data Gateway (HDG) (Al-Jaroodi; Mohamed, 2019; Justinia, 2019; McGhin *et al.*, 2019); a blockchain-based privacy-preserving data sharing (BPDS), a new data preservation system (DPS), a BHEEM framework, and a novel decentralized attribute-based signatures (ABS) scheme, and MediChainTM (Hussien *et al.*, 2019); MedShare (Hussien *et al.*, 2019; McGhin *et al.*, 2019); MedBlock (Hussien *et al.*, 2019; Padmavathi; Rajagopalan, 2019); Fast Healthcare Resources (FHIRChain) (Zhang *et al.*, 2018); A new blockchain-based data scheme (BBDS) for security and privacy preservation for data transactions (Tandon *et al.*, 2020);

OmniPHR (McGhin *et al.*, 2019; Roehrs; Da Costa; Da Rosa Righi, 2017); MediLedger project (Mattke *et al.*, 2019). Further, the Bloodchain prototype, using Hyperledger Iroha and Ardor systems to maintain patient privacy, was developed by Pólvora *et al.* (2020).

Overcoming the barrier of *privacy concerns* not only enhances user confidentiality and preserves sensitive data but also establishes robust information access control mechanisms (Huang *et al.*, 2019; Panarello *et al.*, 2018). This comprehensive approach to addressing privacy in blockchain implementations instills greater confidence among technology providers, business entities, governments, and customers in the security and integrity of information shared on the network.

Addressing the challenge of *lack of reliability in input data* (TB_4), demands a strategic approach that incorporates both technological and procedural solutions. The literature advocates for the **IoT Blockchain integration for data reliability** (Allen *et al.*, 2019; Babich; Hilary, 2020; Brookbanks; Parry, 2024; Olsen; Tomlin, 2020; Rogerson; Parry, 2020; Ziolkowski; Miscione; Schwabe, 2020). This integration or ensuring that data is natively digital makes information collecting more precise and reliable, which is important, especially in situations where data integrity is critical, such as SC&L, and the healthcare sector, among others. These industries can benefit from increased security, traceability, process automation, and decreased fraud thanks to this integration (Agarwal *et al.*, 2022).

Further enhancing data integrity, the **co-certification approach for blockchain transactions**, i.e., certification of transactions by both buyers and sellers, as recommended by Babich and Hilary, 2020), ensures a mutual validation process. Certifying transactions by buyers and sellers involves verifying and documenting transactions in a secure and unchangeable manner on the blockchain. This process fosters transparency and confidence by ensuring that all parties participate in confirming the transactions.

The importance of **establishing mechanisms for data correction, modification, or deletion to maintain high-quality and accurate data** is underscored by Ziolkowski, Miscione and Schwabe (2020). Additionally, the **establishment of reliable third-party verification**, supported by Babich and Hilary (2020), Howson (2020), and Ziolkowski, Miscione and Schwabe, 2020), introduces an additional layer of data validation. Successfully overcoming the barrier of data unreliability not only improves the overall data quality within the system, as indicated by Lu *et al.* (2019), but also contributes to the creation of an incorruptible system, enhancing trust among Supply Chain partners, as noted by Babich and Hilary (2020) and Bai and Sarkis (2020).

The challenge of *immutability* (TB_5), requires a discerning approach to ensure the integrity and flexibility of blockchain systems. Biswas and Gupta (2019) suggest the need for **careful transaction management to navigate the rigidity of immutability**. Addressing this barrier effectively can lead to substantial enhancements across the entire SC. By adopting meticulous transaction practices, the system can maintain the foundational principle of immutability while introducing a degree of flexibility to rectify errors, as highlighted by Pournader *et al.* (2020). This approach also facilitates the removal of inaccurate or privacy-violating data, ensuring compliance with data protection standards, as noted by Babich and Hilary (2020).

Addressing *security problems* (TB_7) in blockchain necessitates a comprehensive and multifaceted approach. The literature outlines several strategies to fortify security measures, beginning with **establishing clear guidelines and requirements**, as suggested by Al-Jaroodi and Mohamed (2019). **Enhancing secure user authentication** is critical for safeguarding access and interactions within the blockchain, a measure advocated by Kim (2020). **Tailoring policies and regulations to segments** requiring heightened protection further strengthens the security framework, as emphasized by Al-Jaroodi and Mohamed (2019). **Encrypting confidential data** is paramount to ensuring privacy and security, a practice supported by Kuo, Kim and Ohno-Machado (2017) and Zhang *et al.* (2018). The **development of robust key management systems and safety mechanisms**, as discussed by Hussien *et al.* (2019) and Hughes *et al.* (2019), alongside the **use of a reliable cryptographic stack** as proposed by Mazzei *et al.* (2020), are essential for maintaining secure blockchain environments. Frizzo-Barker *et al.* (2020) highlight the importance of **pseudonymous Security Measures in Blockchain Adoption**, i.e., anonymity and the use of pseudonyms to protect user identities.

To implement these strategies, various actions are proposed, including the adoption of *Private blockchains* (e.g. Multichain and Bankchain) ensure confidentiality, privacy, and control (Padmavathi; Rajagopalan, 2019; Yang *et al.*, 2020). *Consortium blockchain* (e.g., Hyperledger), which is restricted to the participation of consortium members, improves privacy and security (Feng *et al.*, 2019; Lu *et al.*, 2019).

Formal analysis and verification methods, as discussed by Matsuo (2017) and Zheng, Zhu and Si (2019), alongside key security wallets and consensus mechanisms like Proof-of-Stake (PoS) and credit-based Proof-of-Work (PoW), as suggested by Alam

Khan *et al.* (2020), Lin *et al.* (2017), Lu *et al.* (2019), and Huang *et al.* (2019), further enhance the security infrastructure. The Practical Byzantine Fault Tolerance (PBFT) algorithm, as noted by Lu *et al.* (2019) and Sukheja *et al.* (2019), and the integration of virtual private networks or HIPAA-compatible components, as recommended by Kuo, Kim and Ohno-Machado (2017) and Zhang *et al.* (2018), also contribute to a more secure system.

Additionally, sector-specific solutions, particularly in healthcare, as explored by McGhin *et al.* (2019), address unique security needs. Overcoming the barrier of *security problems* not only ensures data integrity, as highlighted by Panarello *et al.* (2018) but also significantly reduces vulnerabilities to hacker attacks, as noted by Al-Jaroodi and Mohamed (2019). As a result, participants in the Supply Chain can rely on a tamper-proof and secure system, fostering trust and reliability in blockchain's potential to revolutionize Supply Chain Management. Healthcare industry solutions include MedBlock, which is excellent in terms of privacy and security (Fan *et al.*, 2018; Padmavathi; Rajagopalan, 2019); a new blockchain-based data scheme (BBDS) for security and privacy preservation (Tandon *et al.*, 2020); Trial and Precision Medicine, which adds integrity and security of access to medical data (McGhin *et al.*, 2019); and Healthcare Data Gateways [a smartphone (IoT) application], which uses the decentralized nature of blockchain to improve security and data integrity (McGhin *et al.*, 2019).

Tackling the issue of *high latency* (TB8) within blockchain systems demands targeted strategies to enhance speed and efficiency. The literature recommends **augmenting both throughput and latency limits** as fundamental steps to mitigate this barrier, as evidenced by the work of Croman *et al.* (2016) and Alam Khan *et al.* (2020). **Further advancements in mining and processing techniques** are crucial for accelerating blockchain transactions, a notion supported by Salman *et al.* (2019) and Seok, Park and Park (2019). To actualize these strategies, the adoption of multi-chain architectures is proposed by Gonczol *et al.* (2020) to distribute the load and enhance processing speeds. In multi-chain architectures, SKYFChain, with its three-tier architecture, applies a two-step block generation approach to overcome the latency issues of current PoW-based blockchains (Gonczol *et al.*, 2020). The Bitcoin-NG protocol, highlighted by Eyal *et al.* (2016) and Zhao *et al.* (2019), presents a notable reduction in latency compared to traditional Bitcoin, offering a viable solution to the latency challenge. Additionally, integrating software solutions like BigchainDB, as discussed by BigchainDB GmbH (2018) and Zheng, Zhu and Si (2019), combines blockchain's robust features with the efficiency of database systems to improve transaction speeds. Exploring alternative consensus mechanisms to the conventional Proof of Work (PoW), as suggested by Alrubei *et al.* (2020) and Ahl *et al.* (2020), and implementing sharding techniques, as discussed by Lin *et al.* (2017) and Ahl *et al.* (2020), further contribute to reducing latency by partitioning the network and data, allowing parallel transaction processing. Addressing the challenge of high latency leads to a more responsive and efficient blockchain system, significantly improving transaction times and reducing delays, as noted by Kuzlu *et al.* (2019).

Confronting *scalability problems* (TB_9) in blockchain is essential for its widespread adoption and effective functioning within Supply Chains. The literature suggests several strategies to enhance scalability, starting with **enabling interoperability to facilitate seamless communication between different blockchain systems and platforms**, as advocated by Chang, Iakovou and Shi (2020). **Rethinking the blockchain design to make it inherently more scalable** is crucial, a concept explored by Croman *et al.* (2016). Streamlining the blockchain by **retaining only verified transactions in progress and partial data** can also significantly enhance scalability, as proposed by Kuo, Kim and Ohno-Machado (2017) and Zhang *et al.* (2018)**. Employing point-to-point storage networks**, as suggested by Gonczol *et al.* (2020), and **configuring consensus protocols to be more efficient**, as noted by Xu *et al.* (2017), are additional strategies to address scalability. The **use of wallets for transaction management**, highlighted by Mendling *et al.* (2018), and **blockchain-based Internet of Medical Things (IoMT) devices**, as discussed by Hussien *et al.* (2019), contribute to the scalability solutions.

To implement these strategies, various actions are proposed: adopting open-source protocols to encourage innovation and flexibility, as noted by Kim (2020); utilizing Directed Acyclic Graphs (DAGs) to enhance throughput and consensus speed, as explored by Jiang *et al.* (2019) and Huang *et al.* (2019); and considering Double Chain architecture and private blockchains to improve system efficiency, as suggested by Leng *et al.* (2018) and Prasad *et al.* (2018), respectively. Blockchain compression methods and the adoption of Federated, Consortium, and Permission-based Blockchains, as recommended by Bruce (2018), Hussien *et al.* (2019), Padmavathi and Rajagopalan (2019), Zheng, Zhu and Si (2019), Behnke and Janssen (2020), also play a vital role in addressing scalability. Sharding, which involves partitioning the blockchain into more manageable segments, stands out as a significant technique to improve scalability, with contributions from Yu, Liang and Xu (2019), Meyer, Kuhn and Hartmann (2019), and

Vinay Reddy (2019), among others. Network sharding is considered one of the most important techniques to solve the blockchain scalability problem and improve blockchain performance (Huang *et al.*, 2022), which can alleviate the uneven distribution of blockchain transactions to a certain extent.

Sharding allows the system to process transactions in parallel, thus improving scalability (Ahl *et al.*, 2020; Andoni *et al.*, 2019; Meyer; Kuhn; Hartmann, 2019; Panarello *et al.*, 2018; Yu; Liang; Xu, 2019). Furthermore, it is possible to improve blockchain network throughput through the *RAFT algorithm*, which allows for more than 10,000 transactions (Alam Khan *et al.*, 2020).

Solana, a public blockchain platform that was introduced in April 2018, is designed to enhance scalability in comparison to other blockchains while maintaining decentralization and security (Pierro; Tonelli, 2022). Polkadot is a blockchain system linking a network of blockchains, each designated as a parachain, that may be tailored to the corporate needs of a given application (Scott; De Castro Neto; Pinheiro, 2023). Polkadot offers the security, verifiability, and trust of a public blockchain together with the cost benefits, scalability, and control of a permissioned or private blockchain (Scott; De Castro Neto; Pinheiro, 2023).

Leveraging BigChainDB for handling large data volumes, as proposed by Viriyasitavat, Anuphaptrirong and Hoonsopon, 2019), Gonczol *et al.* (2020) and Alam Khan *et al.* (2020), and optimizing storage and redesigning blockchain structures, as discussed by Zheng *et al.* (2018), Mazlan *et al.* (2020), further enhance the scalability of blockchain systems. Successfully overcoming scalability challenges not only improves the storage capacity and transaction processing rate of blockchain, as highlighted by Azzi, Chamoun and Sokhn (2019), Kouhizadeh, Saberi and Sarkis (2021), but also expands the platform's capacity to serve a larger number of participants, as noted by Kuzlu *et al.* (2019).

Solutions for storage optimization and redesigning blockchain to solve the block size problem have mostly been found in the healthcare sector:

a) Storage optimization: mini-blockchain (Bruce, 2018; Mazlan *et al.*, 2020; Zheng *et al.*, 2018), VerSum (Mazlan *et al.*, 2020; Van Den Hooff; Kaashoek; Zeldovich, 2014; Zheng *et al.*, 2018), and Reference Pointer FHIRCain (Mazlan *et al.*, 2020; Zhang *et al.*, 2018);
b) Redesigning blockchain: FHIRChain (Mazlan *et al.*, 2020; Zhang *et al.*, 2018), HealthChain (Ahram *et al.*, 2017; Mazlan *et al.*, 2020), DeepLinQ

(Chang *et al.*, 2019; Mazlan *et al.*, 2020), and Omni PHR (Mazlan *et al.*, 2020; McGhin *et al.*, 2019; Roehrs; Da Costa; Da Rosa Righi, 2017) (as blockchain modeling solutions); short-term data sharing (Mazlan *et al.*, 2020; Zhang *et al.*, 2018) and caching systems (Mazlan *et al.*, 2020; Sanka; Cheung, 2019) (as reading mechanism solutions); Chord algorithm (Al-Jaroodi; Mohamed, 2019; Mazlan *et al.*, 2020), tokenization (Mazlan *et al.*, 2020; Zhang *et al.*, 2018), sharding (Team Zilliqa, 2017); (Mazlan *et al.*, 2020), Practical Byzantine Fault (PBFT) consensus protocol (Team Zilliqa, 2017); (Mazlan *et al.*, 2020), and TrustChain (Mazlan *et al.*, 2020; Otte; De Vos; Pouwelse, 2020) (as write mechanism solutions); and Lightning networks (Mazlan *et al.*, 2020; Poon; Dryja, 2016) (as a bi-directional solution).

Addressing the *need for high computational speed and processing power* (TB_{10}) is crucial for enhancing the efficiency and sustainability of blockchain systems within Supply Chains. The literature offers several strategies to mitigate this challenge. Salman *et al.* (2019) propose the **development of simpler cryptographic schemes** to reduce the computational burden associated with blockchain transactions.

Additionally, the **adoption of a lightweight consensus algorithm**, as suggested by Seok, Park and Park (2019), can significantly lower the demand for processing power without compromising security and integrity. Proof of Stake (PoS), Delegated Proof of Stake (DpoS), and Proof of Block and Trade (PoBT) are examples of some of the lightweight consensus algorithms. The advantage of PoS is that it eliminates the necessity for significant computing capacity and increased electricity consumption, as is the case with PoW (Alam Khan *et al.*, 2020). DpoS is a lightweight consensus algorithm that uses a selected number of elected delegates to validate and confirm transactions, therefore reducing the performance and efficiency loss in IoT blockchain-based systems (Haque *et al.*, 2024). PoBT is a solution that enables the verification of trades and blocks with reduced computational time (Biswas *et al.*, 2020).

The **use of private blockchains**, recommended by Cole, Stevenson and Aitken (2019), presents another viable solution by limiting the network size and, consequently, the computational requirements. Such blockchains can be tailored to the specific needs of the Supply Chain entities, offering a balance between security, privacy, and computational efficiency. Effectively overcoming this barrier not only reduces wasted computing resources, including hardware and electricity, as highlighted by Khan *et al.* (2020) but also facilitates resource savings across the SC.

Addressing *usability problems* (TB_{12}) within blockchain is essential for fostering wider acceptance and utilization across Supply Chains. To mitigate this barrier, **securing senior management support** is paramount, as their endorsement can drive the adoption and integration of blockchain by aligning organizational strategies and resources, a notion supported by Wong *et al.* (2020b). Additionally, **seeking cost-effective and user-friendly solutions** is crucial for lowering the entry barriers to blockchain usage, as emphasized by Hackius and Petersen (2020). Examples that execute these solutions include the "Obsidian" programming language, as discussed by Coblenz (2017) and Alam Khan *et al.* (2020), which offers a more intuitive approach to smart contract development within blockchain systems. Tools such as BitConeView and Bitlodine, highlighted by Yli-Huumo *et al.* (2016), provide user-friendly interfaces for analyzing and visualizing blockchain data, further simplifying the interaction with blockchain. Successfully overcoming usability challenges not only boosts blockchain users' confidence by demystifying technical complexities, as noted by Wong *et al.* (2020a) but also enhances blockchain adherence and proliferation within the Supply Chain sector, as highlighted by Zamani and Giaglis (2018).

The issue of *increased IT handling complexity* (TB_{15}), poses a significant challenge to the broader adoption and implementation of blockchain within Supply Chains. To address this barrier, it is essential **to identify and utilize the right tools**, a strategy underscored by Rane and Narvel (2019). Additionally, the **development of cloud-based blockchain tools**, as advocated by Clohessy and Acton (2019), offers a promising solution to streamline blockchain management and operation. As suggested by Kamilaris, Fonts and Prenafeta-Boldú (2019), the integration of blockchain oracles further enhances the functionality and efficiency of blockchain systems by facilitating the secure and reliable interaction between blockchain networks and external data sources. These advancements simplify the IT complexities associated with managing and operating blockchain systems. Successfully overcoming the barrier of increased IT handling complexity holds significant implications for the entire SC. By reducing the complexity and technical demands of blockchain, the technology becomes more accessible to a wider range of organizations, particularly small and medium-sized enterprises (SMEs) that may have limited IT resources. This accessibility, as highlighted by Clohessy and Acton (2019), not only facilitates the democratization of blockchain but also promotes its wider dissemination across various sectors of the SC.

The challenge posed by *smart contract problems* (TB_{16}) significantly impacts the efficacy and reliability of blockchain within Supply Chains. Although the literature does not provide specific solutions to this barrier, addressing it is crucial for the seamless operation of smart contracts, which are pivotal for automating transactions and agreements within the blockchain. Overcoming the issues related to smart contracts would lead to considerable improvements across the entire SC. One of the primary benefits would be enhanced negotiations among the various stakeholders within the SC. By reducing the vulnerability to code errors in smart contracts, as highlighted by Feng *et al.* (2020), Kumar, Liu and Shan (2020), and Tezel *et al.* (2020), the integrity and reliability of these digital contracts are significantly improved. This enhancement in reliability fosters trust among parties and streamlines the execution of agreements without the need for intermediaries. Moreover, addressing smart contract problems facilitates the automation of processes, making operations more efficient and reducing the likelihood of conflicts between parties. The automation enabled by reliable smart contracts can transform Supply Chain Management by making it more transparent, efficient, and secure.

In wrapping up our analysis of the implementation phase, it's crucial to acknowledge that barriers to *lack of interoperability and standardization* (TB_2), *lack of tools for blockchain implementation* (TB_{11}), and *complexity in system design* (TB_{14}) also manifest during this stage. Given their presence, it becomes imperative to apply the strategies identified in earlier phases that are designed to counteract these specific barriers. The continuity in addressing the *lack of interoperability and standardization* (TB_2), *lack of tools for blockchain implementation* (TB_{11}), and *complexity in system design* (TB_{14}) throughout the implementation phase underscores the importance of leveraging previously outlined mitigation strategies. Employing these strategies within this phase is essential for navigating the challenges they pose, ensuring a smoother transition, and enhancing the overall success of the blockchain implementation process.

During this final stage of the blockchain adoption process, strategies such as putting blockchain into use and confirming the decision to continue using it take place. Firstly, the company must be prepared to receive innovation. In this way, strategies focusing on establishing an effective blockchain governance model, IoT blockchain integration for data reliability, and co-certification approach for blockchain transactions, as well as the other strategies mentioned in this stage, will help with the technology's integration into the organization's operations. Implementing these strategies will improve blockchain performance during pilot tests and PoCs, and successful results at this moment are likely to lead to widespread official approval of the technology. Furthermore, using these strategies significantly minimizes the probability that the organization would decide to discontinue using the technology after deciding to embrace it.

Understanding the barriers that will exist at each stage of the blockchain adoption process benefits adopting organizations in a variety of ways. We can thus emphasize that efforts that mitigate barriers during the initiation stage have a strong potential for reducing initial resistance and giving the organization with a better knowledge of the benefits of blockchain and how it may favorably impact its operations. In the adoption-decision stage, these strategies will assist businesses in making informed decisions, generating arguments that increase confidence in a decision to adopt blockchain. Finally, the strategies used during the implementation stage enable the organization to achieve efficient implementation and optimize the benefits of adopting this technology.

4.5 Conclusions

This section concludes the article by summarizing its main findings, contributions, and implications. It revisits the identified technological barriers to blockchain adoption in supply chain contexts, highlights the role of mitigation strategies across different adoption stages, and reflects on both academic and practical contributions. In addition, the section discusses the limitations of the study and outlines directions for future research in the domain of blockchain adoption in supply chains.

4.5.1 Final Remarks and Contributions

This research conducted an SLR to examine technological barriers in blockchain implementation for Supply Chains and ways to address them. Despite reviewing 155 publications, half were theoretical-conceptual studies, indicating an ongoing immaturity in research. Among the identified 16 technological barriers (Table 4.3), scalability and privacy issues were most frequently cited. The identification of these barriers facilitated the exploration of mitigation strategies.

Our comprehensive study on the integration of blockchain within Supply Chain Management culminates in a framework that strategically addresses the technological barriers across the adoption stages, initiation, adoption decision, and implementation, as proposed by the Diffusion of Innovations (DOI) theory. This framework not only substantiates the theoretical stages of DOI with practical mitigation strategies but also provides a structured methodology for successfully navigating the complex landscape of blockchain adoption. The academic implications of our work are profound, offering a significant extension to DOI theory's application in Supply Chain Management and contributing a refined model to the blockchain literature. This model advances the theoretical understanding of blockchain adoption processes and sets a precedent for future research in this dynamic field.

The human element is a crucial observation that this study should emphasize when discussing the barriers to the adoption of blockchain. The adoption of blockchain is intensive in its relationship with individuals, even though the fact that the study only addresses technological barriers. Consequently, our research assigns the same level of significance to a barrier known as human reluctance to implement blockchain as it does to technological barriers. The decision maker or prospective users of the technology may be hesitant to adopt it due to most of the technological barriers mentioned in this study. Therefore, it is imperative to make coordinated efforts to increase awareness of these barriers, their potential mitigation strategies, and the moment in which they must be confronted.

Human reluctance can be converted into the adoption of technology through the implementation of a well-informed framework. We comprehend that successful blockchain implementations indicate that companies have successfully overcome and advanced adoption barriers, thereby converting human reluctance into technology acceptance.

Practically, our study serves as an important guide for industry practitioners, outlining a series of actionable strategies tailored to facilitate blockchain adoption at various critical junctures. Our findings underscore the importance of addressing specific challenges such as the *black-box effect, interoperability, standardization, scalability, security, and data reliability*. For policymakers and standard-setting bodies, this research provides an evidential basis to support the development of frameworks and regulations that foster the adoption of blockchain.

4.5.2 Academic Contributions

Our research makes significant contributions to academic literature, particularly in the domains of blockchain and the Diffusion of Innovations (DOI) theory. Studies highlight the need for research that investigates the adoption of blockchain in the organizational and decision-making context (Frizzo-Barker *et al.*, 2020; Upadhyay, 2020), and the need for more efforts to understand the stages of the blockchain adoption process (Wamba; Queiroz, 2020). One of the primary academic contributions is the application and extension of DOI theory within the context of blockchain adoption in Supply Chain Management. By mapping out the technological barriers and corresponding strategies to overcome these barriers across the various stages of blockchain adoption as outlined by DOI theory, our study provides a structured and nuanced understanding of the adoption process. This approach enriches the academic discourse surrounding DOI theory and extends its applicability to the burgeoning field of blockchain.

Furthermore, our research contributes to the burgeoning literature on blockchain by examining the specific technological barriers to its adoption within Supply Chain Management. By identifying and categorizing these barriers, our study fills a significant gap in the literature, which often discusses blockchain broadly without delving into the specific challenges that organizations face during the adoption process. This detailed analysis advances our understanding of blockchain's implications for Supply Chain Management and sets the stage for future research to build upon our findings and explore new dimensions of blockchain adoption.

Moreover, our proposed framework provides a structured lens for scholars to examine the complexities of blockchain adoption. It extends the academic dialogue by mapping out a clear trajectory of barrier mitigation strategies, offering a refined model that future research can use to explore the nuanced dynamics of blockchain integration across various industries.

4.5.3 Practical Contributions

On the practical side, our research offers invaluable insights for managers and companies navigating the complexities of blockchain implementation within Supply Chain Management. By outlining strategies to overcome the identified barriers at different phases of the adoption process, our study acts as a guide for practitioners. These strategies, grounded in both literature and empirical findings, provide a roadmap for organizations to navigate the often tumultuous journey of blockchain adoption.

Our proposed framework equips practitioners with a clear understanding of when and how to apply these strategies, thereby enhancing the efficiency, reliability, and security of blockchain within their Supply Chain operations, driving innovation and fostering a competitive edge in the marketplace. For the initiation phase, it suggests foundational actions; for the decision-making phase, it proposes evaluation criteria and commitment strategies; and for the implementation phase, it outlines execution tactics. For example, during the initiation phase, our research highlights the importance of demystifying blockchain to overcome the 'black-box' effect, thus enabling managers to make informed decisions about its adoption. In the adoption-decision phase, we underscore the need for interoperability and standardization, offering strategies for organizations to ensure their blockchain initiatives are compatible with existing and future systems. Finally, in the implementation phase, our study offers solutions for addressing challenges such as scalability, security, and data reliability, which are critical for the successful integration of blockchain into Supply Chain Management operations.

These practical contributions are not only valuable for organizations currently considering or in the process of adopting blockchain but also for policymakers and standard-setting bodies looking to facilitate and regulate blockchain adoption. By providing a clear understanding of the barriers and strategies at each stage of adoption, our research empowers stakeholders across the Supply Chain Management ecosystem to make informed decisions and take proactive steps towards leveraging blockchain's full potential.

4.5.4 Limitations and future research

Like all studies, this research presents some limitations. This topic presents research opportunities arising from elements not covered by our study and the literature. Despite our efforts to comprehensively analyze barriers and strategies, the evolving nature of the field may mean some elements could be absent from our discussion, so the analyzes and examples about strategies to mitigate barriers were not exhausted. Table 4.5 shows future research directions, accompanied by examples of possible RQs. It proposes investigating non-technological barriers, understanding the relationship between barriers and adoption stages, analyzing barrier influence relationships, improving interoperability standards, assessing organizational readiness, integrating blockchain with other systems, addressing skills shortages, clarifying blockchain's comparative advantages, and enhancing understanding and acceptance of blockchain among Supply Chain partners and customers.

Table 4.5 - Future research directions

Directions for future research	Suggested research questions
Investigating non-technological barriers and ways to overcome them	• What are the non-technological barriers to the adoption of BT in SCM? • How to overcome non-technological barriers to the adoption of BT in SCM?
Understanding barriers in specific application contexts	• What are the barriers to adopting BT in Healthcare? How to overcome them? • What are the barriers to BT adoption in SMEs? How to overcome them? • What are the barriers to adopting BT in governments? How to overcome them?
Exploring non-technological barriers in the stages of the BT adoption process	• At what stages during the BT adoption process do non-technological barriers arise?
Establishing the barriers that should be prioritized	• What is the influence relationship between the barriers? • What are the barriers that most influence others? • What are the barriers that should be prioritized?
Developing standards for BT that are globally accepted/ Solving interoperability issues	• How to develop a global/supranational standard for BT solutions?
Investigating the readiness of organizations to overcome barriers	• Are organizations ready to overcome barriers related to BT adoption?
Improving communication between BT and enterprise management systems	• How to improve interoperability between blockchain and ERP? • How to improve interoperability between blockchain and Electronic Data Interchange (EDI)?
Exploring ways to facilitate understanding of how the blockchain works	• How to facilitate understanding of how BT works? • How to open the black-box for understanding the technical fundamentals of blockchain?
Developing human resources to work with BT	• How to improve the qualification of the workforce on BT?

Source: Author’s own work.

5 MITIGATING NON TECHNOLOGICAL BARRIERS TO BLOCKCHAIN ADOPTION IN SUPPLY CHAINS: A STAKEHOLDER-ORIENTED FRAMEWORK[2]

This chapter examines non-technological barriers to blockchain adoption in supply chain networks and the strategies proposed to mitigate them. Based on a systematic literature review and expert validation, the study identifies organisational, interorganisational, and cost related barriers and analyzes how mitigation strategies align with the needs and characteristics of different stakeholders.

5.1 Introduction

Every industrial revolution has brought new opportunities and challenges for various stakeholders, such as customers, managers, employees, financiers, etc. (Vishnubhotla; Pati; Padhi, 2020). Recently, Blockchain Technology (BT) has gained popularity as it has brought revolutionary changes to several industries and Supply Chains (SCs) by allowing the implementation of secure, decentralised, and trustworthy applications (Abdullah; Ibrahim, 2019; Chaudhuri *et al.*, 2022; Fosso-Wamba; Queiroz, 2022; Gong *et al.*, 2022).

Blockchain guarantees trust, immutability/transparency, support for disintermediation, and extra security for transactions on the Internet (Li *et al.*, 2024; Makridakis, 2019; Ramanan; Li; Gebraeel, 2022). Blockchain has the potential for various sectors to benefit from its advantages. The study of blockchain adoption in Supply Chains involves the drivers, adoption barriers, type of application, and adoption stages. For example, blockchain has been used to improve performance and sustainability in agri-food Supply Chains (İndap; Tanyaş, 2025; Vern *et al.*, 2024), as a solution for global vaccine distributions (Yadav; Shweta; Kumar, 2023), and in fashion Supply Chains to support traceability (Moretto; Macchion, 2022). These diverse applications highlight that each sector faces unique barriers and implementation challenges.

Investigating the adoption of blockchain in Supply Chains is a broad process. For example, studies such as Queiroz and Fosso Wamba (2019) and Vu, Ghadge and Bourlakis, 2023) investigate the drivers of blockchain adoption in SC. Dubey,

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[2] This article was written in British English.

Gunasekaran and Foropon (2024) examined how blockchain technology impacts the performance and coordination of humanitarian SC. Pandey and Pathak (2025) study investigated blockchain adoption and resilience in construction Supply Chains. Rauniyar *et al.* (2023) studied the digitisation of global Supply Chains through blockchain. The implications for sustainability from adopting blockchain in Supply Chains were studied by Zhang, Jia and Chen (2024). The stages of adoption, in turn, are generally explained through theories such as the Diffusion of Innovations (DOI) theory, proposed by Rogers (2003), according to a study by Agi and Jha (2022).

Barriers such as high implementation cost, lack of knowledge and expertise, and transparency versus privacy dilemma (Vu; Ghadge; Bourlakis, 2023) play an essential role in blockchain's slow adoption rate (Kouhizadeh; Saberi; Sarkis, 2021). These findings are also corroborated by empirical studies conducted with companies, as highlighted in recent industry reports, such as CAPGEMINI (2021), Deloitte (2022), and World Economic Forum (2020). This leads to poor management of organisational barriers, contributing to blockchain not being implemented in practice, even though many companies are rolling out several prototypes. For example, the discontinuation of the joint initiative between A.P. Moller–Maersk and IBM, called TradeLens, in 2023, demonstrates that several barriers still need to be overcome to achieve full collaboration between stakeholders in Supply Chains.

Queiroz *et al.* (2019) and Dutta *et al.* (2020) recognise that a comprehensive examination of the challenges and barriers limiting blockchain adoption in Supply Chain Management is a research gap. Therefore, we performed a scoping review on the topic, revealing that while numerous studies address technological and non-technological barriers, they often do not distinguish between them, nor do they offer a comprehensive review aggregating these findings into a coherent framework tailored for Supply Chain Management. This lack of clarity and integration in existing research underscored a critical research opportunity. Moreover, given these sector-specific applications and challenges, there is a clear need for an integrative analysis that captures common non-technological barriers while remaining sensitive to industry-specific contexts. This justifies the formulation of our first research question:

RQ_4: What are the non-technological barriers to adopting blockchain in Supply Chains?

Identifying and understanding these non-technological barriers, such as regulatory issues, organisational resistance, and cultural challenges, is essential for providing actionable insights for Supply Chain managers (Yadlapalli; Rahman; Gopal, 2022). This focuses on the operational, regulatory, and organisational challenges that are distinct from the technical aspects of blockchain and crucial for effective implementation (Allen *et al.*, 2019; Wong *et al.*, 2020a).

Identifying non-technological barriers is a crucial initial step in our research on blockchain adoption in Supply Chains. Still, it merely constitutes the beginning of addressing the issues these barriers offer. While it is crucial to acknowledge barriers, it does not necessarily provide the means for overcoming them. Consequently, our investigation must investigate effective strategies to mitigate these barriers, rather than relying on simple identification. This broader perspective is essential because, despite its relevance, knowledge about the barriers is of limited value in the absence of a clear comprehension of practical and applicable strategies for overcoming the barriers. Consequently, we develop our second research question, which is delineated below.

RQ_5: What strategies are proposed in the literature to mitigate these barriers?

Given the dispersion of strategies across various studies without a focused discussion or synthesis, our second research question aims not only to gather but also critically evaluate how existing and potential strategies can specifically address and mitigate the non-technological barriers identified. This deeper analysis seeks to establish clear connections between particular strategies and the barriers they are designed to overcome. By doing so, the study provides Supply Chain managers with targeted tools and methods, enhancing their ability to implement blockchain effectively.

Moreover, the efficacy of any proposed strategy invariably hinges on the alignment and cooperation of various stakeholders involved in or affected by the adoption process (Balci; Surucu-Balci, 2021). The complex dynamics between these stakeholders can significantly influence the successful implementation of blockchain (Yadlapalli; Rahman; Gopal, 2022). As such, merely developing strategies without considering stakeholder needs, interests, and potential resistance would likely result in suboptimal adoption rates and could lead to project failures (Nicolai *et al.*, 2023). Therefore, we have our third research question.

RQ_6: How do these strategies align with the needs and characteristics of various stakeholders in the Supply Chain ecosystem?

This question explores the alignment of mitigation strategies with the diverse needs and influences of various stakeholders within the Supply Chain ecosystem, underpinned by Stakeholder Theory. It seeks to provide a nuanced understanding of stakeholder dynamics, highlighting the necessity for strategic engagement and collaboration (Jang; Yoo; Cho, 2024). Based on the Stakeholders Theory, firms strive to offer various advantages to various stakeholders, including groups and individuals who have the potential to influence or be influenced by the organisation. These stakeholders may include civil societies, communities, customers, employees, governments, shareholders, and suppliers (Freeman, 1984; Harrison *et al.*, 2019).

Although several studies have addressed barriers related to blockchain adoption in Supply Chains (Kumar; Liu; Shan, 2020; Yadav *et al.*, 2020; Zhao *et al.*, 2019), their analyses often remain fragmented. None have provided a comprehensive and systematic enumeration of non-technological barriers nor thoroughly explored effective mitigation strategies. Our research aims to fill this significant gap by delivering a detailed synthesis of barriers and their solutions, positioning this study as a critical resource for industry practitioners and policymakers confronting these challenges. Given the emergent nature of blockchain in Supply Chains and its practical complexities, the insights from this study are especially valuable, providing clarity and actionable guidance in an area still in its developmental stages (Ghode *et al.*, 2020b), (Kummer *et al.*, 2020). Addressing these three interconnected aspects, identifying barriers, developing mitigation strategies, and aligning these strategies with stakeholder interests, creates a robust framework for understanding and enhancing blockchain adoption in Supply Chains. Each step builds on the previous one, forming a comprehensive approach that addresses the multi-faceted challenges of blockchain implementation.

Specifically, the study identifies 29 distinct non-technological barriers, categorises them into three overarching groups (intra-organisational, inter-organisational, and cost-related), and proposes targeted mitigation strategies for each barrier. These strategies are further organised into analytical meta-categories to facilitate managerial application. Additionally, the study establishes clear links between each strategy and the relevant stakeholders involved in implementation, using Stakeholder Theory as a guiding lens. As a result, we propose an integrated decision-making framework that offers both theoretical and practical contributions to the field of blockchain adoption in Supply Chain Management.

The paper is organised into five sections. Section 5.2 refers to the theoretical foundation. Section 5.3 describes the research methodology. Section 5.4 presents the findings. Section 5.5 provides an analysis of stakeholders' involvement in addressing non-technological barriers. Finally, Section 5.6 summarises the conclusions of this research.

5.2 Blockchain and Stakeholder Theory

Stakeholder Theory, initially introduced by R. Edward Freeman, in 1984, has become one of the most extensively utilised theories in blockchain and Supply Chain Management across various industries, including patent protection, intellectual property rights systems, healthcare, agri-food Supply Chains, auditing and assurance services, and the public sector (Zhu; Bai; Sarkis, 2022). Freeman (1984) defined a stakeholder as any group or individual that influences or is influenced by the achievement of a company's objectives. Stakeholder Theory posits that companies must acknowledge the significant influence of stakeholders and react to demands for practices that enhance their competitive position (Freeman, 2001).

Blockchain-based Supply Chain applications involve several stakeholders facing diverse internal and external pressures for technology adoption (Zhu; Bai; Sarkis, 2022). The attributes of transparency, immutability, and traceability provide numerous advantages that directly influence the demands and expectations of stakeholders. Customers and consumers can affect a company's choice to adopt a new technology (Zhu; Bai; Sarkis, 2022). The consensus in the research indicates that blockchain necessitates robust collaboration across stakeholders (Lee; Olson; Trimi, 2012; Nicolai *et al.*, 2023). To accomplish this, participants in Supply Chains must collaborate (Di Vaio; Varriale, 2020). In executing a blockchain project, it is crucial to evaluate stakeholder readiness, specifically the willingness and capacity of diverse stakeholders to embrace the new technology, both individually and collectively (Nicolai *et al.*, 2023; Savage *et al.*, 2010).

Blockchain is effective when the key stakeholders engaged in its implementation are ready and willing to use it (Nicolai *et al.*, 2023). Due to the decentralised nature of blockchain, all stakeholders must participate in the chain with designated roles (Leng *et al.*, 2023; Nicolai *et al.*, 2023). Consequently, the support of influential stakeholders and comprehension of blockchain facilitate adoption (Balci; Surucu-Balci, 2021). Nonetheless, the same authors observed that the adoption of blockchain -based systems by ecosystem stakeholders is not occurring at the same pace. This study will employ Stakeholder Theory, which underscores the necessity of recognising all stakeholders in the adoption of blockchain, rather than concentrating solely on shareholders or investors.

Identifying stakeholders who play a vital role in the adoption of blockchain and their role in mitigating barriers to adoption is critical (Balci; Surucu-Balci, 2021), given that stakeholders form the foundation of the blockchain network (Nicolai *et al.*, 2023).

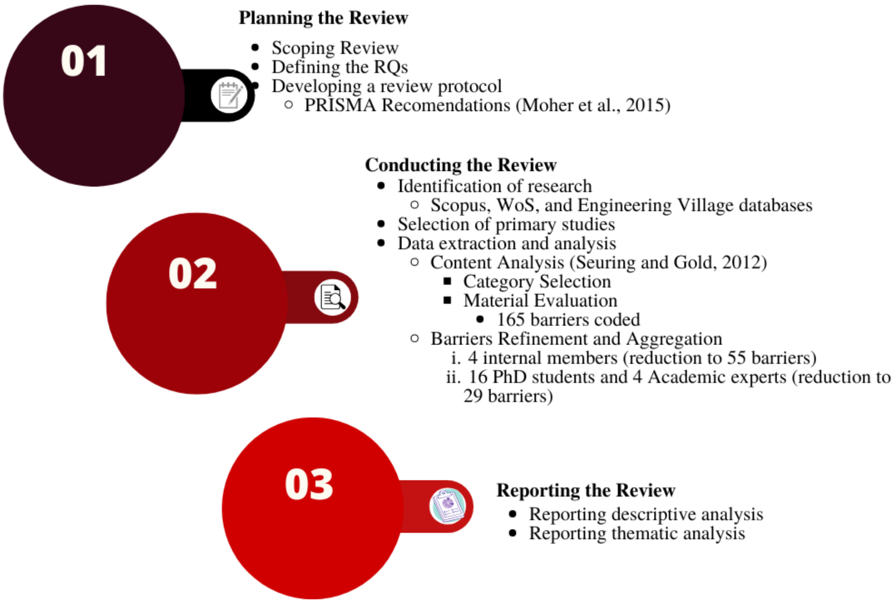
Stakeholders are generally classified into two groups: internal and external (Jang; Yoo; Cho, 2024; Sarkis; Gonzalez-Torre; Adenso-Diaz, 2010). Internal stakeholders, according to Jang, Yoo and Cho (2024), might be senior management and employees of firms, while external stakeholders include public or social groups, communities, and governments. According to Stakeholder Theory, these players can include consumers, suppliers, employees, investors, communities, and civil society members who can influence or be influenced by company activities (Freeman, 2001). Additional stakeholders identified by other authors encompass shippers, carriers, freight forwarders, customs authorities, ports, banks, insurance companies, and pertinent governmental entities (Balci; Surucu-Balci, 2021; Loh *et al.*, 2020). Balasubramanian *et al.* (2021) described the key stakeholders in the adoption of blockchain as: governments, business entities, blockchain solution providers, and customers/end users.

5.3 Research method

A practical review advances knowledge and enables the exploration of areas where research is needed (Webster; Watson, 2002b). This study employs a Systematic Literature Review (SLR), guided by a structured three-stage process defined in Tranfield, Denyer and Smart (2003) and Kitchenham and Charters (2007) (Fig. 5.1).

Before this SLR, however, a preliminary scoping review was crucial in shaping the research questions that guided the systematic review. This initial scoping phase helped identify broad themes and gaps in the existing literature regarding blockchain in Supply Chains, specifically focusing on non-technological barriers and strategies for their mitigation.

Figure 5.1 - The SLR process used in the present research



Source: Author's own work.

5.3.1 Planning the review

Initially, the scoping review informed the formulation of our research questions, as presented in the introduction. Scoping reviews are beneficial for exploring nascent evidence when it remains uncertain what additional, more specific inquiries may be effectively formulated and addressed by a more focused systematic review (Armstrong *et al.*, 2011; Munn *et al.*, 2018). This phase involved examining a wide range of literature to understand how blockchain barriers and strategies were being discussed, which often lacked a clear distinction between technological and non-technological aspects. For this investigation, we searched for articles utilising the terms: Blockchain, SC, barriers, and mitigation strategies.

Munn *et al.* (2018) advocate for conducting scoping reviews as a first step to systematic reviews and identifying and analysing knowledge gaps; hence, we employed a scoping review to delineate the research questions for our study. This scoping study revealed research potential that led to the formulation of our three research topics, which have been elaborated upon in depth before. This preliminary exploration was essential to design a focused review protocol that targets specific gaps identified during the scoping review.

After this, we delve into designing the review protocol of our SLR. The review protocol guides the search for articles in scientific databases. A predefined protocol reduces the possibility of researcher bias (Kitchenham; Charters, 2007). Based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations (Moher *et al.*, 2015), we developed our research protocol, defining the research topics, the keywords, and the scientific databases that characterise the search strategy, the timeframe for article retrieval, as well as the article inclusion/exclusion criteria.

To establish search term parameters, we initially performed pilot searches, during which it became apparent that articles discussing barriers did not consistently incorporate terms such as "barrier," "challenge," or "obstacle." Indeed, various alternative terminologies may be employed to denote the constraints that hinder the implementation of blockchain within Supply Chain organisations. We decided to exclude barriers from our search terms to retrieve a more significant number of pertinent articles.

Thus, the research terms refer to blockchain in the context of Supply Chain management (SCM) and operations management (OM). The search strings were: (“blockchain” OR “BCT” OR “distributed ledger* technology” OR “DLT”) AND (“supply chain” OR “value chain*” OR “supply network*” OR “management” OR “operations” OR “production” OR “logistics”).

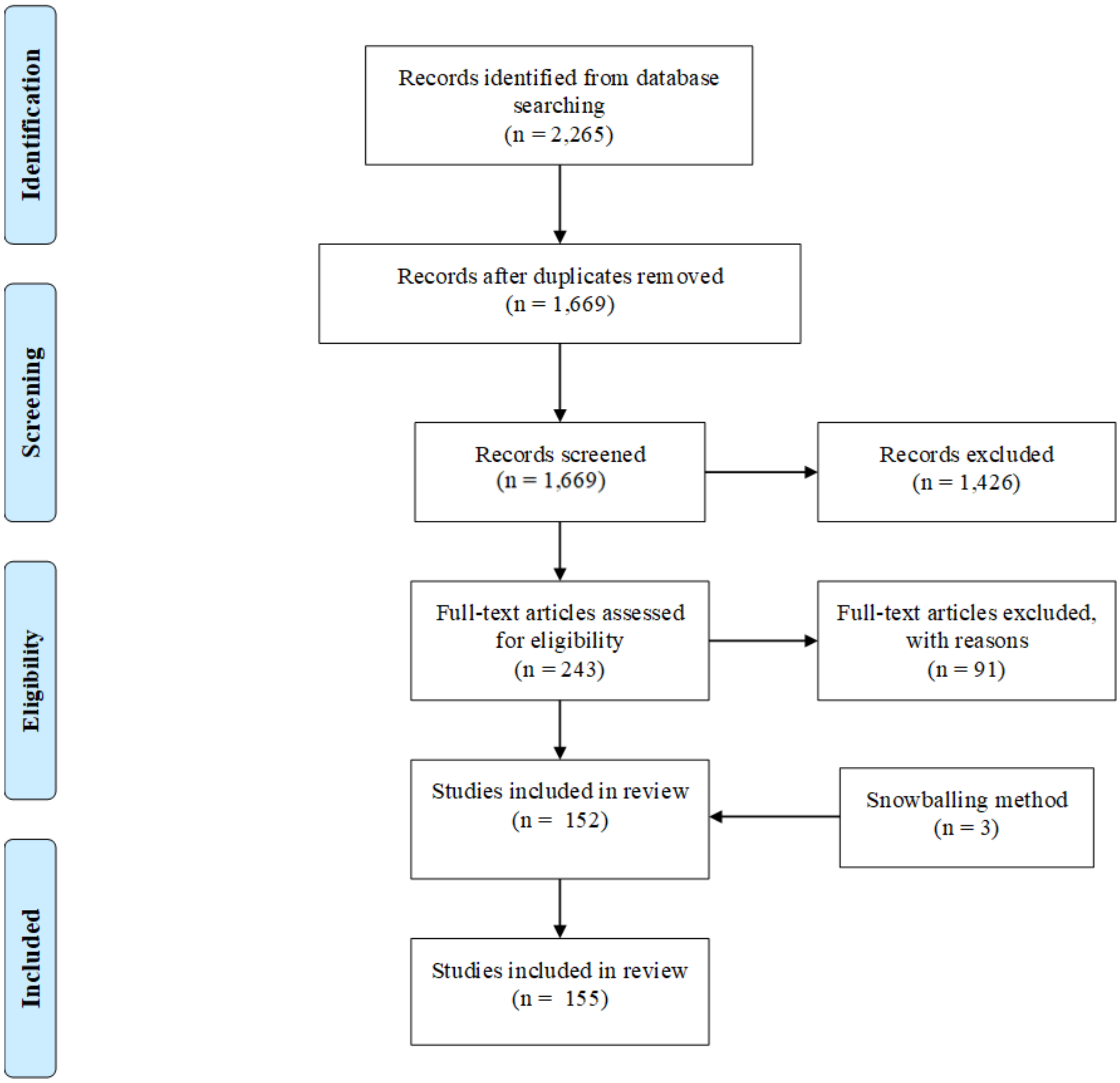
Regarding scientific databases, Webster and Watson, (2002) suggest that the leading journals in the field are the most important sources of information. Therefore, the articles were searched using the Web of Science and Scopus, the two most extensive databases conventionally used in literature reviews. We also added a third database, Engineering Village, the leading platform of Compendex, which is the most comprehensive database for engineering literature. Specifically, the search in the Web of Science was conducted in the Core Collection, considering the databases available through the institutional access of the authors’ affiliations, and included articles published up to the year 2025, with no initial date delimitation.

Finally, regarding inclusion/exclusion of articles, it was decided that articles that met the following criteria would be included: (1) articles addressing barriers to adopting blockchain in Supply Chain Management and strategies to mitigate them; (2) articles published in journals; (3) articles written in English; and (4) articles to which full access was possible.

5.3.2 Conducting the review

Using the review protocol, we searched the databases, obtaining 2,265 articles. Of these, 596 duplicate papers were removed (Fig. 5.2), leaving 1,669 papers. Duplicate articles were found due to the search being performed across various databases that include overlapping information. To guarantee the precision of the review, duplicates were detected and eliminated. Duplicates were detected by analysing titles, authors, publication years, and DOIs utilising the Mendeley bibliographic management software. A manual verification was thereafter conducted to ensure accurate exclusion.

Figure 5.2 - PRISMA flow diagram



Source: Author’s own work.

Considering that not all the remaining papers might be relevant to our study, we screened them to assess their relevance. The 1,669 articles were analysed based on the title, abstract, and keywords in this step. Several studies with a purely technical, mathematical, and computing science focus were excluded from the analysis as they were outside the scope of our research. Two reviewers conducted this step to decrease subjectivity in the choice and to increase the reliability of the article retention or removal process. When it was impossible to analyse an article's relevance in this step, we retained it for full reading in the next phase. After this screening process, 243 papers (which met the four inclusion criteria) were selected for a full review.

After selecting the relevant articles, we conducted a content analysis (CA) to review these studies. A CA makes it possible to conduct rigorous, systematic, and reproducible literature reviews (Seuring; Gold, 2012). We applied the category selection and material evaluation steps proposed in Seuring and Gold (2012) study.

The categories analysed in the articles selected for review were defined in the category selection stage. First, we conducted a keywording stage through an exploratory analysis of 15 articles that mentioned the terms barriers or challenges in their titles to generate an initial list of keywords to guide the CA process. The keywords defined in this step were used to create the analysed categories.

Next, we moved on to the material evaluation stage, in which all relevant articles were analysed according to previously defined categories. After this review, 152 articles were retained, and another three articles were included using the snowballing approach. Thus, a total of 155 papers were meticulously examined (See appendix A). The material evaluation process allowed new keywords to emerge and to be added to the initial categories, so this coding cycle was repeated whenever a new relevant keyword was found, either giving rise to a new category or being incorporated into an existing category.

The material evaluation was conducted to group categories that responded to the two RQs. To answer RQ_4, we reviewed those articles looking for non-technological barriers related to adopting blockchain. In this context, internal barriers to the organisation, barriers associated with the external environment, and financial barriers were highlighted. Technical barriers, such as scalability and interoperability issues, were not addressed. Regarding RQ_5 and RQ_6, we analysed the articles looking for strategies that enable the mitigation of non-technological barriers.

5.3.3 Reporting the review: Content analysis and expert validation

In the reporting stage, the findings that answer the RQs are highlighted (see Section 5.4.1).

Non-technological barriers to the adoption of blockchain were detected through a comprehensive study of 155 papers. The data extraction process included meticulously reviewing the complete content of these articles to identify references to barriers, obstacles, or challenges not directly associated with technological issues, yet capable of impacting the implementation and dissemination of this technology. Factors including social, economic, cultural, regulatory, organisational, and behavioural elements that impede or postpone the adoption of blockchain were examined. All elements pertaining to such barriers were carefully retrieved and cataloged.

A total of 165 non-technological barriers to the adoption of blockchain were compiled from the examination of the 155 articles. Members of the internal research team subsequently thoroughly examined these barriers to improve and validate the categories found. In addition to other elements that needed to be changed, like the explanation of ambiguous ideas, the correction of imprecise definitions, and the removal of duplications, the researchers discovered several inconsistencies and redundancies during this procedure.

Additionally, barriers were categorised according to content similarity, with the objective of consolidating categories that addressed analogous issues or impediments, however articulated in varying manners or terms within the articles. The process of regrouping and refinement enabled us to decrease the overall number of initially discovered barriers, culminating in 55 different barriers. The decrease primarily resulted from the observation that, despite various barriers being identified under different terminologies in the literature, many pertain to analogous or interconnected underlying issues, hence warranting the consolidation of these categories into a fewer number of barriers.

Following the identification and consolidation of the 55 barriers, the refinement process was enhanced through collaboration with a group of 16 PhD students in industrial engineering and four academic experts (Table 5.1). The participants, chosen for their expertise in Industry 4.0, blockchain, and Supply Chain Management (SCM), were crucial in validating and enhancing the barrier categories, offering their theoretical and pratica insights, which were fundamental for improving the analysis.

Table 5.1 - Academic experts

Expert	Position	Academic education	Research area of expertise	Years of experience with blockchain
1	Researcher/Professor	PhD in Industrial Engineering	Operations Management and Supply Chain Management	6
2	Researcher/Professor	PhD in Industrial Engineering	Operations Management and Supply Chain Management	6
3	Researcher/Professor	PhD in Industrial Engineering	Operations Management and Supply Chain Management	6
4	Researcher/Professor	PhD in Engineering	Operations Management and Supply Chain Management	7

Source: Author's own work.

The refinement phase had two main stages: a detailed examination of the barriers and a review of definitions and categorisation, involving a structured collaborative process. The 16 PhD students were assigned to perform a comprehensive and critical examination of the 55 identified barriers. They were requested to offer feedback regarding the clarity and pertinence of barriers to blockchain adoption within the Supply Chain context. Furthermore, the students were urged to recognise potential overlaps among the barriers, propose the incorporation of previously unconsidered barriers, and evaluate the terminology employed to describe the barriers, aiming for enhanced precision and consistency. This process of evaluation and review allowed the refinement of definitions and elimination of conceptual redundancy or ambiguities.

Additionally, four academic experts, owning PhDs and substantial research expertise in Industry 4.0, blockchain, and supply chain management, were requested to assess the barriers from both applied and theoretical viewpoints. The experts conducted an in-depth review of the categories, emphasising advanced concepts and practical situations, to ensure that the barriers accurately reflected the challenges encountered by the Supply Chain in adopting blockchain. In this phase, the experts modified the definitions, proposing conceptual revisions and the restructuring of categories. The refinement process resulted in a reduction of barriers to 29.

After meticulous study, the experts determined that the identified barriers could be properly classified into three main categories: intra-organisational, inter-organisational, and cost-related (Fig. 5.3). They considered these categories most suitable for classifying the barriers, considering the complex nature of the challenges faced in the implementation of blockchain. Intra-organisational barriers were defined as obstacles within organisations, including cultural, structural, and behavioural issues that impede the application of blockchain. Inter-organisational barriers refer to the obstacles encountered in contacts among various organisations, including a lack of trust, collaboration difficulties, and regulatory issues. Finally, cost-related barriers pertain to economic obstacles, including high implementation costs and uncertainty regarding the financial benefits of technology adoption.

Following finding, categorising, and validating the barriers, we performed an extensive literature review to identify specific mitigation strategies for each barrier. The investigation of mitigation strategies involved a thorough examination of the selected publications to determine proposed approaches applicable to each previously identified barrier. The strategies identified for each barrier were cataloged. The information derived from the articles was organised into a matrix, correlating the barriers with their respective mitigation strategies, so facilitating a clear representation of potential solutions to the highlighted issues.

Subsequently, the barriers and their corresponding mitigation strategies underwent a thorough examination and analysis conducted by an expert panel. This methodical procedure involved virtual meeting where experts were invited to critically evaluate the barriers and the suggested strategies. Throughout the discussions, the experts modified the strategies, proposed enhancements, and identified possible limitations. This panel led to a significant enhancement of the mitigation strategies.

A qualitative content analysis was conducted to identify recurring themes and patterns within these mitigation strategies. Based on this analysis, the strategies were grouped into broad analytical meta-categories, defined through the identification and synthesis of key themes, objectives, and contexts of application. These categories were refined through iterative reviews conducted by the internal research team to ensure consistency and applicability. Finally, the strategies were classified into their corresponding meta-categories.

5.3.4 Design propositions

This section addresses RQ_6. The process of generating research propositions occurred in two phases. First, stakeholders involved in the implementation of blockchain in Supply Chains were identified, and they would play critical roles in overcoming the identified barriers. After identifying the stakeholders, the next step was to develop the research propositions.

Based on the identified barriers and mitigation strategies, we conducted an analysis to determine the stakeholders involved in blockchain adoption. Thus, the mitigation strategies were examined to identify players or groups of actors who were commonly cited as being responsible for the execution or facilitation of these strategies. As a result, we compiled a preliminary list of stakeholders who would either influence or be impacted using blockchain in Supply Chains. The stakeholders were thereafter categorised according to their functions and roles in the mitigation methods.

The process of generating research propositions was founded on a comprehensive review of non-technological barriers to blockchain adoption, strategies for mitigation, and the identification of relevant stakeholders. This study led to the formulation of research propositions that explore how stakeholders may collaborate to surmount these barriers and promote the integration of blockchain in Supply Chains.

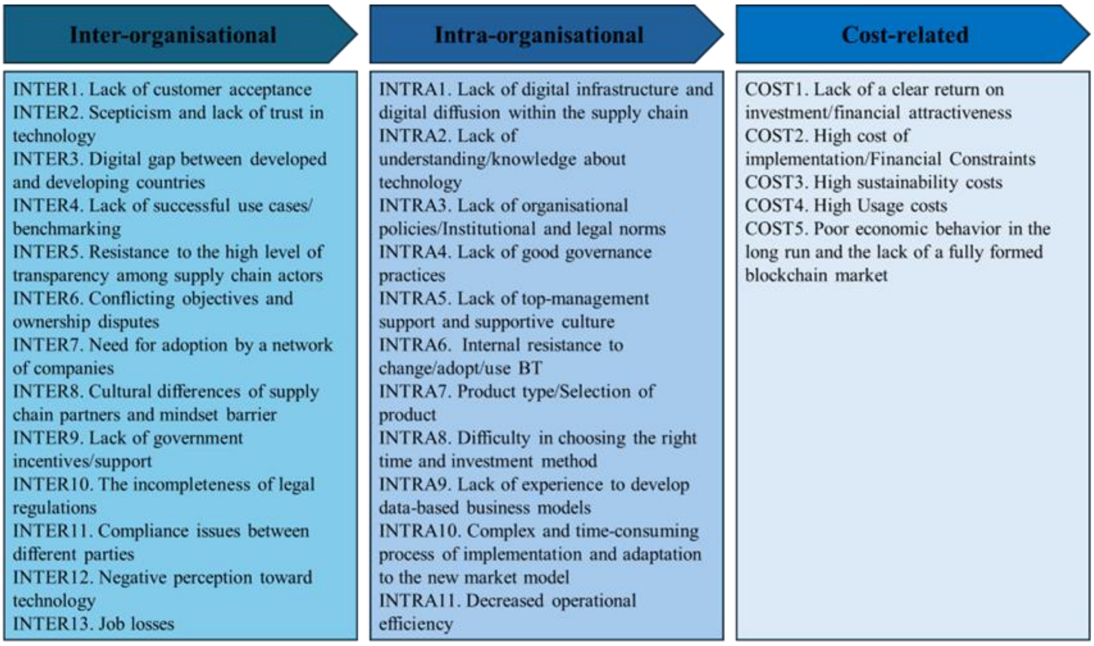
5.4 Findings

This section presents the main findings of the study, focusing on the identification of non-technological barriers to blockchain adoption in supply chain contexts and the strategies proposed to mitigate them. The results are structured into inter-organisational, intra-organisational, and cost-related categories, and analyzed in relation to stakeholder needs and adoption challenges.

5.4.1 The non-technological barriers for blockchain adoption in the Supply Chain

The barriers to adopting blockchain in Supply Chain Management can be classified as inter-organisational, intra-organisational, systems-related/technical, and external (Li *et al.*, 2020; Saberi; Kouhizadeh; Sarkis, 2019). Our study did not address systems-related/technical barriers, as this is a vast subject that deserves a separate and in-depth analysis. We, therefore, classified non-technological barriers as inter-organisational, intra-organisational, and cost-related. We allocated the external barriers to the inter-organisational category and added the cost-related category (despite being among the intra-organisational barriers, we assumed that a separate category would be essential to address financial restrictions). Figure 5.3 presents the identified barriers.

Figure 5.3 - Non-technological barriers



Source: Author's own work.

The inter-organisational category addresses relationship barriers with Supply Chain partners and external barriers [arising from governments, industries, institutions, communities, and non-governmental organisations (NGOs)] (Kouhizadeh; Saberi; Sarkis, 2021). Table 5.2 provides the definition of barriers classified in this group.

Table 5.2 - Inter-organisational barriers

Inter-organisational Barrier	Definition	References*	Papers quantity
Lack of customer acceptance (INTER1)	The lack of awareness and adoption of BT is a big challenge, and many people do not understand how it works (Meng *et al.*, 2018). Customers' lack of awareness and perceptions of BT can hinder its mass adoption (Saberi; Kouhizadeh; Sarkis, 2019).	[1; 3; 14; 29; 49; 62; 63; 78; 86; 100; 136; 139; 144; 145; 151; 153; 154]	17
Scepticism and lack of trust in technology (INTER2)	BT's impact is difficult to predict, but awareness of it is still low, and much scepticism exists (Wong *et al.*, 2020a). Compared to other industries, SC&L companies are more sceptical about using BT (Kamble; Gunasekaran; Arha, 2019). Organisations involved in SC networks depend on each other for information, products, and money flow; creating transparency in this relationship requires building trust before adopting BT, which is a challenge (Ghode *et al.*, 2020b).	[5; 7; 10; 12; 17; 19; 20; 21; 22; 23; 31; 40; 42; 55; 68; 72; 93; 94; 97; 98; 107; 125; 128; 138; 145; 146; 150; 151; 152; 154; 155]	31

Inter-organisational Barrier	Definition	References*	Papers quantity
Digital gap between developed and developing countries (INTER3)	When it comes to digital competence and access to technology, there seems to be a gap between developed and developing countries (Kamilaris; Fonts; Prenafeta-Boldύ, 2019), and notably, there are highly differing standards (Gonczol *et al.*, 2020). This gap can inhibit BT adoption in global SCs.	[38; 52; 147]	3
Lack of successful use cases/benchmarking (INTER4)	Assessing the long-term consequences of blockchain projects when there are no examples is complex, and there is little useful information on the results of blockchain testing (Hackius; Petersen, 2020). Convincing business cases are also scarce (Kamilaris; Fonts; Prenafeta-Boldύ, 2019). Knowledge of BT benefits is still limited to those involved in technology and those whose industries are adopting their solutions (Rane; Narvel, 2019).	[6; 7; 10; 12; 19; 20; 29; 38; 40; 49; 52; 53; 62; 63; 68; 73; 75; 79; 87; 98; 99; 100; 103; 111; 115; 116; 117; 120; 122; 124; 127; 132; 155]	33
Resistance to the high level of transparency among SC actors (INTER5)	A significant challenge is to convince partners and customers to provide their data (Wang *et al.*, 2019), mainly due to confidentiality issues whereby companies need to remain resilient when sharing private information with potential competitors (Galvez; Mejuto; Simal-Gandara, 2018).	[36; 45; 57; 94; 99; 106; 122; 127; 141; 143; 154; 155]	12
Conflicting objectives and ownership disputes (INTER6)	Interest conflicts make companies reluctant to share information with other members. The transparency enabled by blockchain contributes to the organisation's reluctance to use it to store and share information (Wan; Huang; Holtskog, 2020). What happens when two users claim ownership of the same asset? Ownership disputes are problems related to blockchain governance because they stem from the blockchain's authentication (Ziolkowski; Miscione; Schwabe, 2020).	[66; 122; 127; 135; 155]	5
Need for adoption by a network of companies (INTER7)	The adoption of a DLT is not a decision made by a single organisation, so a network of companies must decide to cooperate on a blockchain-based infrastructure (Zamani; Giaglis, 2018). Owing to its distributed nature and complexity, BT's success depends on compliance and the general agreement between the different parties involved in the SC; this also implies a strong dependence on blockchain operators (Gonczol *et al.*, 2020).	[1; 3; 5; 7; 15; 19; 29; 33; 34; 38; 60; 62; 63; 64; 66; 67; 75; 80; 83; 88; 93; 99; 100; 106; 116; 117; 127; 128; 132; 136; 138; 140; 141; 142; 147; 149; 154]	37
Cultural differences among SC partners and mindset barriers (INTER8)	Cultural differences indicate that customers and partners may have different mindsets, hindering blockchain integration and SC transparency (Kouhizadeh; Saberi; Sarkis, 2021). Companies will need to work in other areas that can be uncertain and often risky (Zamani; Giaglis, 2018). How companies seek to overcome mindset barriers will play a vital role in this disintermediation process (Zamani; Giaglis, 2018).	[6; 21; 25; 29; 62; 63; 72; 79; 94; 96; 106; 127; 132, 141; 151; 152; 153]	17
Lack of government incentives/support (INTER9)	The lack of government incentives is one of the reasons why companies are not looking for solutions in BT (Clohessy; Acton, 2019).	[19; 86; 136; 138, 141; 143; 146]	7
The incompleteness of legal regulations (INTER10)	BT does not yet have a set of general rules and regulations that should be followed. Thus, regulatory uncertainties and the illegal use of blockchains can occur (Feng *et al.*, 2020). The absence of formal legal frameworks can make BT complex and delay implementation (Attaran; Gunasekaran, 2019). The lack of acceptance by legal and regulatory authorities, coupled with the lack of user acceptance, limits BT's development and commercial adoption (Hughes *et al.*, 2019).	[1; 4; 5; 6; 7; 11; 12; 15; 16; 17; 18; 19; 23; 24; 25; 27; 28; 29; 30; 31; 32; 34; 36; 38; 39; 40; 44; 46; 47; 48; 52; 53; 62; 63; 66; 67; 70; 71; 73; 75; 76; 78; 79; 82; 83; 88;	70

Inter-organisational Barrier	Definition	References*	Papers quantity
		93; 99; 101; 102; 105; 106; 108; 111; 114; 115; 116; 117; 120; 124; 127; 128; 130; 133; 140; 142; 150; 152; 154; 155]	
Compliance issues between different parties (INTER11)	This concerns the uncertainty surrounding regulations, standards, and agreements related to the sharing of manufacturing data, which can be a sensitive issue for many manufacturers (Lee; Azamfar; Singh, 2019).	[24; 28; 32; 38; 70; 144]	6
Negative perception of technology (INTER12)	The literature highlights this barrier as participation in the underground economy, illegal activities, unethical behaviour, and selfish mining. Organisations may hesitate to adopt BT because it is associated with malicious developments and uses in underground economies (Biswas; Gupta, 2019) (Kouhizadeh; Saberi; Sarkis, 2021). Terrorists use BT's anonymity to commit illegal acts (Vilkov; Tian, 2019).	[3; 6; 11; 22; 28; 29; 34; 62; 63; 83; 85; 94; 97; 107; 111; 118; 120; 124; 127; 153]	20
Job losses (INTER13)	Due to disintermediation, BT can leave many people and entities without work (Vilkov; Tian, 2019). Middle- and low-income workers in accounting, verification, banking, and other areas may lose their livelihoods owing to BT's automation potential (Hald; Kinra, 2019).	[9; 39; 41; 52; 59; 120]	6

Source: Author's own work.
*Correspondent references are provided in Appendix A.

The intra-organisational category refers to internal barriers to organisational practices (Kouhizadeh; Saberi; Sarkis, 2021). Table 5.3 defines the barriers classified in this group.

Table 5.3 - Intra-organisational barriers

Intra-organisational Barrier	Definition	References*	Papers quantity
Lack of digital infrastructure and digital diffusion within the SC (INTRA1)	Some organisations suffer from the lack of important resources that can hinder the successful adoption of BT; these resources mainly include the Internet and the information technology (IT) infrastructure (Kouhizadeh; Saberi; Sarkis, 2021).	[12; 19; 29; 30; 36; 37; 52; 61; 62; 63; 71; 79; 81; 88; 97; 100; 103; 106; 125; 128]	20
Lack of understanding/knowledge about technology (INTRA2)	The inability to effectively manage innovation inhibits BT adoption (Zamani; Giaglis, 2018). This barrier is one of the possible reasons why companies hesitate to implement blockchain and adopt a "wait and see" attitude (Lambourdiere; Corbin, 2020). The scarcity of professionals with skills, knowledge, and experience in adopting and using BT in the SC is an important challenge to consider (Zhao *et al.*, 2019).	[3; 4; 7; 10; 14; 15; 17; 18; 19; 24; 25; 28; 29; 33; 35; 38; 43; 48; 49; 52; 53; 56; 57; 59; 63; 69; 70; 71; 72; 75; 78; 79; 81; 96; 97; 98; 99; 100; 103; 108; 111; 115; 116; 117; 122; 124; 125; 128; 132; 133; 136; 137; 138; 141; 145; 146; 147; 151; 152; 153; 154]	61
Lack of organisational policies/institutional and legal norms (INTRA3)	It is still unclear who governs transactions, rules, and policies in blockchain-based SCs (Saberi *et al.*, 2019). Clear organisational policies for BT are required by	[9; 29; 62; 63; 125; 138; 141; 151; 152; 155]	10

Intra-organisational Barrier	Definition	References*	Papers quantity
	the manufacturers and retailers, who are the technology users (Farooque *et al.*, 2020).		
Lack of good governance practices (INTRA4)	As the information will be shared and used throughout the network, if there are no good governance practices, some users may operate unreliable, thus reducing trust in the system (De Filippi; Mannan; Reijers, 2020).	[19; 21; 22; 23; 25; 28; 34; 46; 57; 67; 73; 96; 97; 98; 115; 144]	16
Lack of top-management support and supportive culture (INTRA5)	Successfully implementing any SC practice depends on the support of senior management (Saberi; Kouhizadeh; Sarkis, 2019) (Kurpjuweit *et al.*, 2021). If business owners are not fully committed to taking on the risks involved in adopting blockchain, they cannot act as a critical motivating factor in transforming the organisation (Mathivathanan *et al.*, 2021).	[7; 18; 29; 62; 63; 66; 67; 86; 109; 124; 137; 138; 141; 144; 151; 152; 154]	17
Internal resistance to change/adopting/using BT (INTRA6)	Adopting new systems implies the alteration/replacement of legacy systems, which can cause resistance and hesitation in organisations (Kouhizadeh; Saberi; Sarkis, 2021). Furthermore, many companies feel that their current information sharing is functioning perfectly well (Wan; Huang; Holtskog, 2020).	[18; 25; 26; 29; 37; 46; 59; 62; 63; 66; 86; 96; 99; 111; 122]	15
Product type/selection of products (INTRA7)	The cost of the solution may exceed the benefits for products with little added value (Rogerson; Parry, 2020). Depending on the type of product, the function of the blockchain in the SC will be different. Therefore, BT should be adopted for products that enable recovering investments and making a profit (Ghode *et al.*, 2020b).	[5; 21; 22; 97]	4
Difficulty in choosing the right time and investment method (INTRA8)	There is the risk of either investing in inefficient or immature technological trends or postponing investments, potentially leading to companies not following key trends and losing the opportunity to position themselves effectively in the market (Kodym; Kubáč; Kavka, 2020).	[59]	1
Lack of experience in developing data-based business models (INTRA9)	Current business models are focused on product marketing, and companies and executives do not have much experience in developing data-based business models. They, therefore, may not have the necessary resources to collect enough data to generate value (Kodym; Kubáč; Kavka, 2020).	[16; 59]	2
Complex and time-consuming process of implementation and adaptation to the new market model (INTRA10)	BT's introduction will change how companies operate, so they will face difficulties and take time to adapt to the new market model (Lu *et al.*, 2019). Migrating to BT (performing tasks such as moving existing contracts, business documents, and structures) requires a lot of money and high executive commitment over a significant period (Hughes *et al.*, 2019; T, 2020). This process is always challenging for traditional companies due to the learning curve (Yang *et al.*, 2020).	[9; 24; 32; 46; 72; 85; 95]	7
Decreased operational efficiency (INTRA11)	BT can add new activities to traditional systems, such as collecting additional data on a batch level (e.g., scanning parcels) for uploading (Sternberg; Hofmann; Roeck, 2021). SC agents may believe that these extra activities undermine operational efficiency.	[106; 141]	2

Source: Author's own work.
*Correspondent references are provided in Appendix A.

The cost-related category is related to blockchain implementation disbursements, maintenance, and economic behaviour over time. Table 5.4 provides the definition of barriers classified in this group.

Table 5.4 - Cost-related barriers

Cost-related Barrier	Definition	References	Papers quantity
Lack of a clear return on investment/financial attractiveness (COST1)	There are risks for organisations that implement BT, as large financial and human investments are required, and it is difficult to predict whether there will be a return on these investments (Zamani; Giaglis, 2018).	[7; 53; 61; 116; 117; 122; 132]	7
High cost of implementation/financial constraints (COST2)	The initial cost of implementing BT is high and includes new infrastructure and a trained team (Demir *et al.*, 2020; Yadav *et al.*, 2020). This is considered a significant challenge for BT implementation throughout the SC (Kouhizadeh; Saberi; Sarkis, 2021). Organisations have scarce financial resources, and gathering information along the SC and converting to new systems imposes costs on organisations (Kouhizadeh; Saberi; Sarkis, 2021).	[6; 12; 18; 19; 24; 25; 26; 29; 32; 36; 37; 43; 48; 58; 59; 61; 62; 63; 64; 66; 68; 70; 71; 72; 73; 74; 79; 81; 83; 84; 86; 87; 92; 93; 95; 96; 98; 99; 103; 106; 109; 113; 116; 117; 120; 124; 126; 127; 128; 134; 136; 137; 138; 140; 141; 143; 145; 146; 148; 150; 151; 152; 153; 155]	64
High sustainability costs (COST3)	The energy consumption for computing and communication required for blockchain operations is high (Feng *et al.*, 2020). Most of the energy is consumed in two different ways: (1) a large amount of electricity is required for the mining process, and (2) further electricity is consumed in peer-to-peer communications, which requires an edge device to be powered (Zhao *et al.*, 2019). In addition, blockchain mining requires high computational power and has a high cost of transmission delay (Biswas; Gupta, 2019).	[3; 6; 7; 11; 19; 20; 24; 26; 28; 30; 32; 34; 39; 50; 54; 60; 64; 77; 78; 90; 93; 96; 99; 104; 111; 115; 119; 120; 121; 123; 128; 129; 131; 133, 138; 150; 152; 153; 154; 155]	40
High usage costs (COST4)	The processing behind the blockchain, where the entire transaction history is replicated across all nodes, is computationally expensive (Hughes *et al.*, 2019). Each transaction generates a marginal transaction cost, the impact of which on the company's profits will depend on the quantity handled in the SC and/or the goods sold (De Giovanni, 2020). The usage costs include transaction, running, marginal, storage, and maintenance costs.	[6; 12; 13; 15; 24; 31; 32; 37; 46; 51; 59; 78; 80; 87; 89; 91; 110; 115; 138; 143].	20
The lack of a fully formed blockchain market (COST5)	BT's long-term behaviour brings uncertainty. Users currently do not need to pay any fees to use a blockchain network; however, an increase in its adoption may saturate the network, charging subscription fees for each user (Biswas; Gupta, 2019). The lack of a fully formed blockchain market can cause price volatility and fluctuating exchange rates, and the questionable hype around blockchain adoption may jeopardise the success of its future adoption (Biswas; Gupta, 2019).	[11; 29; 53; 100; 115; 118; 124; 132; 137; 142; 153]	11

Source: Author's own work.
*Correspondent references are provided in Appendix A.

5.4.2 Mitigating the non-technological barriers to blockchain adoption in the SC

This section addresses RQ_5. The strategies to mitigate the barriers are first summarised in figures, following which we provide detailed comments. The strategy consists of theoretical suggestions highlighted in the literature to alleviate barriers, which are not necessarily in use, or approaches, technological resources, partnerships, and projects already existing or under investigation, which can overcome barriers.

5.4.2.1 Mitigating inter-organisational barriers

The literature covers mitigation strategies for all barriers. Table 5.5 summarises these results.

Table 5.5 - Strategies to mitigate inter-organisational barriers

Barrier	Strategies (Reference)
$INTER_1$. Lack of customer acceptance	(S1) Promote dissemination of convincing use cases (Jain *et al.*, 2020). (S2) Develop digital platform company partnerships (Ahl *et al.*, 2020). (S3) Promote user interaction (Prosumers/Consumers) (Ahl *et al.*, 2020). (S4) Searchability among nodes (Ahl *et al.*, 2020).
INTER2. Scepticism and lack of trust in technology	(S5) Raise awareness about the technology (Wong, Tan, *et al.*, 2020). (S6) Acquire the right knowledge (Wong, Tan, *et al.*, 2020). (S7) Develop the infrastructure (Wong, Tan, *et al.*, 2020). (S8) Obtain regulatory guidance (Wong, Tan, *et al.*, 2020). (S9) Frame appropriate government regulation regarding blockchain adoption (Yadav *et al.*, 2020). (S10) Sign a collective agreement between UN member countries (Yadav *et al.*, 2020). (S11) Create stakeholder awareness (Yadav *et al.*, 2020). (S12) Use encryption of sensitive data (Kuo *et al.*, 2017; Zhang *et al.*, 2018). (S13) Store confidential data off-chain (R. Yang *et al.*, 2020). (S14) Establish procedural and substantive restrictions related to governance off-chain (De Filippi *et al.*, 2020). (S15) Establish appropriate mechanisms for issuing and authenticating digital identities (Al-Jaroodi; Mohamed, 2019).
INTER3. Digital gap between developed and developing countries	(S16) Investing in training and technology transfer to stakeholders in developing areas (Kamilaris *et al.*, 2019).
INTER4. Lack of successful use cases/ benchmarking	(S17) Measure and compare the effectiveness of using blockchain in sharing information (Wan *et al.*, 2020). (S19) Analyse and disseminate use cases, business models, the benefits and functionality of BT (Zamani; Giaglis, 2018; Clohessy; Acton, 2019; Hackius; Petersen, 2020; L.-W. Wong, Tan, *et al.*, 2020; Tezel *et al.*, 2020; van Hoek, 2020). (S20) Examples of the use of BT by companies in their SC operation (Kshetri, 2018).
INTER5. Resistance to the high level of transparency among SC actors	(S21) Develop a clear policy on what types of data should be disclosed (Galvez *et al.*, 2018). (S22) Promote government-led initiatives forcing the use of blockchain platforms (Wang *et al.*, 2019). (S23) Design an access control structure in a transparent system (Huang *et al.*, 2019). (S24) Seek information hiding using smart contracts embedded in blockchain (Wan *et al.*, 2020).

Barrier	Strategies (Reference)
INTER6. Conflicting objectives and ownership disputes	(S25) Align stakeholder interests (Kurpjuweit *et al.*, 2021). (S26) Adhere to local jurisdiction and implement measures to reassign legitimate ownership (Ziolkowski *et al.*, 2020).
INTER7. Need for adoption by a network of companies	(S27) Consider ways of meeting regulatory obligations in different jurisdictions (Allen *et al.*, 2019). (S28) Identify the particularities of countries and adjust their marketing policies and decisions (Fosso Wamba *et al.*, 2020). (S29) Collaborative efforts to further test BT and increase its adoption (RBC Investor&Treasury, 2018; Kumar *et al.*, 2020). (S30) Shared solutions (Prasad *et al.*, 2018).
INTER8. Cultural differences of SC partners and mindset barrier	(S31) Promote a culture change (Demir *et al.*, 2020). (S32) Encourage organisational learning, unlearning, and relearning (Zamani; Giaglis, 2018).
INTER9. Lack of government incentives/support	(S33) Seek support by Organs regulatory bodies (Nayak; Dhaigude, 2019).
INTER10. The incompleteness of legal regulations	(S34) Define appropriate government regulation regarding the adoption of the blockchain (Yadav *et al.*, 2020). (S35) Develop cooperation and dialogue between public and private institutions (Lin, 2019). (S36) Promote changes in existing public, criminal, private, financial, and regulatory laws (Mariappan, 2019). (S37) EU policy on consumer data (Andoni *et al.*, 2019). (S38) Collaborative decisions between countries (Pally; Reddy, 2019).
INTER11. Compliance issues between different parties	(S39) Develop an information disclosure policy among SC partners (Kouhizadeh *et al.*, 2021). (S40) Promote agreement on the rules (Mackey *et al.*, 2019).
INTER12. Negative perception toward technology	(S41) Develop bidding and bidding procedures for smart contracts in auctions (Tezel *et al.*, 2020). (S42) Promote a change in mindset in people involved in adopting BT (Queiroz; Fosso Wamba, 2019; Ghode *et al.*, 2020). (S43) Improve transparency and accountability (Frizzo-Barker *et al.*, 2020).
INTER13. Job losses	(S44) Develop the ability to unlearn and relearn (Zamani; Giaglis, 2018).

Source: Author's own work.

Mitigating lack of customer acceptance barrier INTER$_1$

Greater *dissemination of convincing use cases* of the benefits of blockchain can reveal the benefits of blockchain to its users (Behnke; Janssen, 2020). Regarding public acceptance, trust in blockchain is important (Ahl *et al.*, 2020). Users must stay current on blockchain risks and opportunities (Wong *et al.*, 2020a). This strategy highlights practical and successful applications of blockchain, reduces customer uncertainty, and builds trust in its value. In doing so, it addresses the need for stakeholder transparency and education by promoting information dissemination and the development of a reliable reputation.

Developing *digital platform company partnerships* can increase convenience and customer engagement, so organisations should invest in partnerships with companies with a strong presence in platform markets, e.g., Amazon and Alibaba (Ahl *et al.*, 2020; World Energy Council, 2018). Partnerships with these already legitimised platforms can expand public reach and familiarity with blockchain-based solutions. The positive influence of well-established actors helps to strengthen inter-organisational collaboration and value co-creation.

Searchability among nodes can improve trust and user-friendliness, a feature that startups and companies like Google are exploring (Ahl *et al.*, 2020; Castillo, 2019). The Blockchain ETL (extract, transform, load) project, available on Google BigQuery, was developed by the Google Cloud developer advocate Allen Day and allows users to search entire transaction ecosystems (Castillo, 2019). While Amazon and Microsoft are concerned with making it easier to build blockchain applications, Day is concerned with exposing how the blockchain is being used and by whom; for blockchain to become mainstream, it will be necessary to give up some of its anonymity features (Castillo, 2019). This strategy promotes a high level of transparency and traceability, enabling consumers, partners, and other stakeholders to access clear and detailed information about each transaction and movement within the SC.

Mitigating scepticism and lack of trust in technology barrier $INTER_2$

Raising awareness about the technology, acquiring the right knowledge, developing the infrastructure, and obtaining regulatory guidance are necessary (Wong *et al.*, 2020a). These are essential strategies that, together, foster trust, reduce scepticism, and create a secure and collaborative environment for the effective adoption of blockchain in Supply Chains. Signing *a collective agreement between UN (United Nations) member countries* and international acceptance could mitigate uncertainty about blockchain's future and increase user confidence (Yadav *et al.*, 2020). These authors believe that the broad international use of blockchain facilitates adoption, while the reverse is also true. Collaboration is critical to blockchain's successful implementation in the Supply Chain (Hastig; Sodhi, 2020). Multilateral agreements act as catalysts for trust, reducing scepticism by conveying institutional stability and diminishing uncertainties about the future of the technology, thereby reinforcing stakeholders' perception of security.

In their study on the agricultural SC, Yadav *et al.* (2020) mentioned the need to create *awareness* among agro-stakeholders about the use of blockchain through appropriate government measures. The creation of awareness among stakeholders, promoted through governmental measures, reduces scepticism by clarifying the value and reliability of blockchain through legitimate institutional sources. Yadav *et al.* (2020) expect that the academic community will develop security, privacy, and interoperability solutions, thus reducing users' scepticism. As blockchain matures and new use cases emerge, the tools that help managers make design, evaluation, and implementation decisions will evolve (Bai; Sarkis, 2020).

The *encryption of sensitive data* is recommended to mitigate this barrier (Kuo; Kim; Ohno-Machado, 2017; Zhang *et al.*, 2018). This strategy ensures data protection, reducing concerns about information leakage or unauthorised access. It aims to safeguard the legitimate rights and interests of stakeholders, thereby addressing issues such as scepticism and lack of trust in blockchain technology.

Before designing the solution, it is necessary to effectively determine what type of information should be stored *on-chain* that can be accessed by the public (e.g., the status of each asset) (Yang *et al.*, 2020), as well as what data should be kept *off-chain* and kept secret (e.g., the private and confidential data of interested parties) (Kuo; Kim; Ohno-Machado, 2017; Yang *et al.*, 2020; Zhang *et al.*, 2018). The distinction between public and private data on the blockchain reduces scepticism by balancing transparency with the protection of sensitive information, thereby promoting trust and security among stakeholders. To ensure an adequate trust level in blockchain, a series of *procedural and substantive restrictions related to governance off-chain*, addressing states of normality and conditions of exception, should be introduced (De Filippi; Mannan; Reijers, 2020). This strategy reduces scepticism and lack of trust in the technology by demonstrating that blockchain can operate under clear principles of equity, predictability, and institutional control.

Blockchain needs to solidify better safeguards to stabilise the industry, allowing insiders and outsiders to distinguish between good and bad players (Prasad *et al.*, 2018). Different entities will trust blockchain transactions when *appropriate mechanisms for issuing and authenticating digital identities* are established (Al-Jaroodi; Mohamed, 2019). New blockchain protocols, governance structures, consensus mechanisms, and use cases often emerge (Kurpjuweit *et al.*, 2021). These mechanisms reaffirm that blockchain is not an uncontrolled system, but rather an environment that can be regulated, audited, and trusted, conditions that are key to overcoming resistance to its adoption.

Mitigating digital gap between developed and developing countries barrier $INTER_3$

The digital divide between the developed and developing worlds delays blockchain adoption in the Supply Chain (Gonczol *et al.*, 2020). In their study addressing the agri-food SC, Kamilaris, Fonts and Prenafeta-Boldú (2019) stressed the need for *training and technology transfer* to developing farmers, aiming to generate real solutions for specific conditions restricting their socio-economic progression. This strategy addresses the root of the problem by empowering local stakeholders with technical knowledge and the minimum necessary infrastructure to operate blockchain-based solutions. This reduces technological asymmetry and promotes inclusion.

Mitigating lack of successful use cases/benchmarking barrier $INTER_4$

Companies are still analysing blockchain's capabilities and potential, so gaining senior management support is difficult without documented performance in real industry situations (Wan; Huang; Holtskog, 2020). Efforts to *measure and compare the effectiveness of using blockchain in sharing information* can help blockchain implementation in Supply Chains (Wan; Huang; Holtskog, 2020). This strategy helps mitigate the barrier of lack of successful use cases by generating practical and reliable evidence that supports its adoption in Supply Chains.

The literature recommends that *use cases, business models, and the benefits and functionality of blockchain should be analysed and disseminated* (Clohessy; Acton, 2019; Hackius; Petersen, 2020; Tezel *et al.*, 2020; Van Hoek, 2019, 2020b, 2020a; Wong *et al.*, 2020a; Zamani; Giaglis, 2018). This strategy helps reduce uncertainty and creates practical benchmarks that strengthen the adoption of blockchain in Supply Chains. The general public needs information about blockchain's benefits and functionality (Tezel *et al.*, 2020).

Some *companies are using* blockchain *in their operations along the SC*. Everledger is a digital transparency company providing technology solutions with a blockchain platform for diamond transparency and traceability (Everledger, 2021). The collaboration between Walmart and IBM to create "Farm to Fork" for food traceability (Yadav; Singh, 2020) is another example in the SC. This problem is expected to be resolved as many implementation projects are being developed in various sectors (Karapetyan *et al.*, 2019). Real cases such as those mentioned demonstrate the practical viability of blockchain, providing validated benchmarks that reduce uncertainties and strengthen its adoption in Supply Chains.

Mitigating resistance to the high level of transparency among Supply Chain actors barrier INTER$_5$

Defining the types of data that should be disclosed is important (Galvez; Mejuto; Simal-Gandara, 2018). Some manufacturers keep their formulas as business secrets and may be reluctant to share them, so *a clear policy on what types of data should be disclosed or kept confidential* could bring security and help them decide (Galvez; Mejuto; Simal-Gandara, 2018). A clear definition of which data should be disclosed or kept confidential reduces resistance to transparency by providing assurance regarding the protection of strategic information, thereby balancing visibility and competitiveness among Supply Chain actors.

The government forcing the use of blockchain platforms can attract organisations and help overcome this resistance (Wang *et al.*, 2019). In our study, the lack of government incentives/support was also identified as a barrier, so by overcoming this barrier it would be possible to mitigate some of this resistance. Government intervention, whether through mandatory implementation or incentives, reduces resistance to transparency by establishing equitable rules, strengthening trust in the system, and balancing responsibilities among Supply Chain actors.

The coexistence of transparency and privacy in blockchain can be a disadvantage due to the confidentiality of sensitive data; therefore, *designing an access control scheme in a transparent system* is necessary (Huang *et al.*, 2019). This strategy helps mitigate resistance to transparency by ensuring that sensitive data remains protected, balancing auditability and privacy among Supply Chain partners.

Focusing on *information hiding using smart contracts embedded in blockchain* in parallel with information sharing within a Supply Chain is necessary (Wan; Huang; Holtskog, 2020). In medical services, sharing information such as medical diagnoses and prescriptions can generate resistance to blockchain implementation, as professionals would perceive this as a threat to their autonomy (Wan; Huang; Holtskog, 2020). The design of the solution framework should consider the development of smart contracts that hide certain information (e.g., the names of doctors/hospitals) without compromising the integrity of the data (in cases where the patient wishes to get second opinions from other hospitals), and grant access upon request (Wan; Huang; Holtskog, 2020). The use of smart contracts to selectively conceal sensitive information mitigates resistance to transparency by protecting stakeholders' autonomy while maintaining data integrity and traceability within the SC.

Mitigating conflicting objectives and ownership disputes barrier $INTER_6$

The involvement and commitment of interested parties are essential, and managers should adopt a supply network rather than an intra-organisational perspective. Accordingly, finding the right partners, building effective governance structures, and aligning stakeholder interests will be possible (Kurpjuweit *et al.*, 2021). By encouraging cooperative governance and coordinated decision-making in blockchain implementation, a Supply Chain approach and stakeholder alignment lessen disputes and competing objectives.

Blockchain needs to *adhere to local jurisdiction and implement measures to reassign legitimate ownership* as a solution for cases where two users claim ownership of the same resource. For this, a well-defined data management architecture is required (Ziolkowski; Miscione; Schwabe, 2020). Identifying actors who resolve conflicts when multiple users claim the same property is essential (Ziolkowski; Miscione; Schwabe, 2020). By avoiding overlapping interests, legitimising rights, and guaranteeing legal security for all chain participants, this strategy helps reduce conflicts.

Mitigating need for adoption by a network of companies barrier $INTER_7$

Mitigation strategies for the problem of adoption and information sharing should *consider ways of meeting regulatory obligations in different jurisdictions* (Allen *et al.*, 2019). Managers of companies operating in a global market must *identify the particularities of countries and adjust their marketing policies and decisions*, considering that countries behave differently when adopting blockchain (Fosso Wamba; Queiroz; Trinchera, 2020). Businesses can adopt blockchain more systematically by tailoring their strategies to the laws and realities of each nation, which makes it easier to build the network required for the technology to work effectively.

Countries' monetary authorities can develop *collaborative efforts to test* blockchain *further and increase its adoption*. To accelerate the integration-led initiative between Asian markets, the Monetary Authority of Singapore (MAS) and the Hong Kong Monetary Authority (HKMA) are collaborating to test blockchain in the multi-trilliondollar industry of global financial commerce to develop an infrastructure to facilitate international transactions (Kumar; Liu; Shan, 2020; RBC Investor&Treasury, 2018). Monetary authorities' cooperative efforts hasten the development of shared infrastructure and foster trust among businesses, facilitating the network adoption required for blockchain success.

Recent developments in regulatory easing, collaborations between organisations, and new developments in more efficient blockchain architectures are significant (Morkunas; Paschen; Boon, 2019). *Shared solutions* are needed, requiring governance and consensus around technology options (Prasad *et al.*, 2018). Consortia and collaborations are being operated, e.g., R3CEV, the Hyperledger Project, and the Post Trade Distributed Ledger Group (Prasad *et al.*, 2018). Resources and knowledge should be shared with competitors and technology providers if necessary, enabling faster cycles for blockchain projects (strong and win–win collaboration) (Prasad *et al.*, 2018). The establishment of consortia, the sharing of resources, and the alignment of technologies among firms foster trust and mitigate risk, so boosting collaborative blockchain adoption and addressing the necessity for coordinated agreement throughout the network.

Supply Chain integration can only occur after blockchain adoption, a paradox (Kouhizadeh; Saberi; Sarkis, 2021). Consortium industries and IT companies are expected to drive the development of blockchain, first creating blueprints for blockchain adoption by the member firms and subsequently developing the infrastructure, platforms, and products for rolling out blockchain within target industry segments (Kumar; Liu; Shan, 2020). With the increasing participation of governments, companies, and technology providers, blockchain will reach higher levels of adoption (Mariappan, 2019).

Mitigating cultural differences of Supply Chain *partners and mindset barrier barrier INTER$_8$*

To trust in a decentralised system, it is necessary to promote a culture change (Who; Team, *[S.d.]*). Researchers must investigate how corporate culture changes after blockchain's introduction and how this differs from other technologies (Mendling *et al.*, 2018). Empirical methods will be needed for research in this area, and insights from organisational science and business research should be informative in this context (Mendling *et al.*, 2018). Promoting a culture of change equips organisations to remove mental barriers and synchronise practices among partners, so aiding in the surmounting of cultural opposition to the collective adoption of blockchain.

Organisational learning, unlearning, and relearning are essential actions and must be present in organisations, i.e., they need to become flexible to work on different issues that can be risky and uncertain, constantly evaluating themselves in terms of changing needs and adaptations (Zamani; Giaglis, 2018). This strategy helps develop an open, adaptable, and collaborative organisational mindset, which is essential to overcoming cultural differences and mental resistance among partners in blockchain adoption.

Mitigating lack of government incentives/support barrier $INTER_9$

The *support that can be provided by regulatory bodies* that formulate the policies and laws that directly impact Supply Chain Management initiatives can help blockchain implementation (Nayak; Dhaigude, 2019). In his study on maritime shipping, Yang (2019) stated that to drive its blockchain-based transformation, coordinating government regulatory systems is necessary, especially customs clearance and management, and establishing a government support and review system. Public policies that incorporate financial incentives, adaptable regulatory frameworks, and governmental cooperation mitigate risks, diminish entry barriers, and promote blockchain usage in Supply Chains.

The government should promote the use of blockchain and provide formal support through intellectual property protection, rules and guidelines for its use, taxation metrics, and punishment for fraudulent activity (Sydow; Sunny; Coffman, 2020). Kenya has proactively addressed these concerns by forming a National Task Force to determine how the nation should move forward in promoting blockchain use (Sydow; Sunny; Coffman, 2020).

Mitigating the incompleteness of legal regulations barrier $INTER_{10}$

Addressing the integration of the IoT and formulating regulations and policies is necessary for all blockchain applications for technology to become a standard choice for future industrial, government, and financial transactions (Gonczol *et al.*, 2020). Blockchain’s legal aspects must be studied/treated from the perspective of the law so that viable solutions and regulations are created to support it (Al-Jaroodi; Mohamed, 2019).

It is imperative to *define appropriate government regulation regarding the adoption of the blockchain* (Frizzo-Barker *et al.*, 2020; Hughes *et al.*, 2019; Kamble; Gunasekaran; Sharma, 2020; Kamilaris; Fonts; Prenafeta-Boldύ, 2019; Karapetyan *et al.*, 2019; Moraes; Cernev, 2020; Tezel *et al.*, 2020; Yadav *et al.*, 2020; Yang, 2019).

Studying and regulating blockchain from a legal perspective facilitates the establishment of precise legal frameworks, mitigating ambiguities and permitting its secure implementation in regulatory contexts that remain incomplete. A legal and regulatory framework capable of monitoring the application of blockchain is necessary (Feng *et al.*, 2020). Managers, IT companies, and academics must come together to study and develop a framework for regulating blockchain and suggest it to political actors (Sheel; Nath, 2019). In his work on food law, Ching-Fu (2019) mentioned the need for a more technologically informed policy-making process. Creating a regulatory environment that improves security with blockchain depends on *cooperation and dialogue between public and private institutions* (Ching-Fu, 2019). When the public and private sectors work together, they can make rules that are clear, realistic, and up to date. This fills any number of legal gaps and makes it easier to use blockchain.

In the energy sector, Andoni *et al.* (2019) presented the new *European Union (EU) policy on consumer data*, in which blockchain users must be identified to account for their responsibilities; however, consumer or commercial information must remain confidential. Policies like this make the law clearer and more certain, which helps to make up for the fact that blockchain regulations aren't full. Regarding *collaborative decisions between countries*, the US, Australia, the UK, Canada, Switzerland, and Malta are at the forefront of formulating a regulatory approach favourable to adopting blockchain (Mariappan, 2019). This partnership encourages regulatory harmonisation, stimulates local laws, and accelerates the process of closing in legal gaps in blockchain.

Mitigating compliance issues between different parties barrier $INTER_{11}$

It is necessary *to develop an information disclosure policy among Supply Chain partners* (Kouhizadeh; Saberi; Sarkis, 2021). Defining who will participate in the blockchain, how data will be validated, and whether sensitive and confidential data will be shared among Supply Chain participants requires building a consortium of interested parties that can agree *on these rules* before a solution can be developed (Mackey *et al.*, 2019). The success of a distributed technology depends on compliance and general agreement between the links in the Supply Chain (Gonczol *et al.*, 2020). Setting clear standards for participation and distributing duties through consortia helps the participants in the chain follow the rules and avoid problems over compliance.

Mitigating negative perception toward technology barrier $INTER_{12}$

Bitcoin's bad reputation and association with illegal activities can inhibit blockchain adoption (Andoni *et al.*, 2019). Initially, the media characterised cryptocurrencies as unethical, owing to their association with trading on the dark web (e.g., illicit weapons and drugs) and the large amount of energy required to process a Bitcoin transaction (Frizzo-Barker *et al.*, 2020). Given the blockchain's association with Bitcoin, Supply Chain members may be reluctant to adopt it.

Bidding procedures for smart contracts in auctions can increase efficiency and transparency, enabling auditing by any participant in the network and thus combating ethical issues (Tezel *et al.*, 2020). This strategy builds trust and legitimacy by making sure that everyone knows what to expect and that the processes are clear and fair. Blockchain adoption requires a revolutionary paradigm shift in the SC, demanding the transmission of skills so that the people involved *change their mindset* and can become professionals (Ghode *et al.*, 2020b; Queiroz; Fosso Wamba, 2019). This method helps individuals understand how important human capital and organisational culture are for developing trust and cooperation. It also gets stakeholders ready to accept and value the changes that technology brings.

Transparency and accountability can help to combat blockchain use for illegal activities, building trust or exposing the unethical behaviour of Supply Chain participants (Frizzo-Barker *et al.*, 2020; Wang *et al.*, 2019). This improves stakeholder trust by making operations and choices clearer, easier to find, and easier to check, which lowers doubts and negative perceptions. The lack of a centralised financial authority to monitor blockchain transactions leads to this problem persisting (Biswas; Gupta, 2019). As the use of blockchain matures and use cases are made public, this should no longer be an issue (Andoni *et al.*, 2019).

Mitigating job losses barrier $INTER_{13}$

The replacement of human labour and the consequent unemployment is a concern when dealing with technologies in the organisational environment. Traditional intermediaries must be able *to unlearn and relearn* so they can leverage their experience and expand their service portfolio to include blockchain-based offerings (Zamani; Giaglis, 2018). This phenomenon has also marked all previous technological revolutions, which required new skills and abilities in Supply Chain Management departments (Kamilaris; Fonts; Prenafeta-Boldύ, 2019). Professionals need to be able to unlearn and relearn to adapt to new technologies and processes. This will help reduce the negative effects of automation and the changes that blockchain brings. This strategy also promotes resilience and professional reskilling, turning possible losses into chances for progress. Along with radical changes in existing markets, new technologies also imply the emergence of new markets and opportunities (Grigoreva; Garifova; Polovkina, 2019).

5.4.2.2 Mitigating intra-organisational barriers

The literature presents strategies to mitigate all intra-organisational barriers. Table 5.6 summarises these results.

Table 5.6 - Strategies to mitigate intra-organisational barriers

Barrier	Strategies (Reference)
INTRA1. Lack of digital infrastructure and digital diffusion within the SC	(S1) Acquire the right knowledge and develop the infrastructure (Wong; Tan, 2020). (S2) Companies should seek to understand how the BC can augment existing processes and whether it can be adapted to the existing infrastructure (Wong; Tan, 2020). (S3) Seek government support (Al-Jaroodi; Mohamed, 2019). (S4) Improve technology readiness (Wong; Tan, 2020). (S5) Using scanners and Wi-Fi connection (Sternberg *et al.*, 2021).
INTRA2. Lack of understanding/knowledge about technology	(S6) Encourage adhesion of key members from across the organisation (Zamani; Giaglis, 2018). (S7) Perform real-time case studies (Drljevic *et al.*, 2020). (S8) Seek new talent (Zamani; Giaglis, 2018; Hastig; Sodhi, 2020; Wong; Tan, 2020). (S9) Professionals must develop blockchain capabilities internally (Kurpjuweit *et al.*, 2021). (S10) Find partnerships via Outsourcing (Wong; Tan, 2020). (S11) Share knowledge with SC partners and regulators (Mariappan, 2019; Fosso Wamba *et al.*, 2020). (S12) Promote national initiatives and government-supported education and training (Al-Jaroodi; Mohamed, 2019; Tezel *et al.*, 2020). (S13) Search for platform transparency and user-friendliness (Ahl *et al.*, 2020; Sheel; Nath, 2020). (S14) Pilot projects (van Hoek, 2019a). (S15) Software development to make BT easier (Kamilaris *et al.*, 2019). (S16) University blockchain training and programs (Ahl *et al.*, 2020).
INTRA3. Lack of organisational policies/Institutional and legal norms	(S17) Clarify policies related to the use of BT in SC processes (Saberi, Kouhizadeh, Sarkis, *et al.*, 2019; Farooque *et al.*, 2020; Wong; Tan, 2020). (S18) Define what is the proper use of technology and also where and when it should be used (Kouhizadeh *et al.*, 2021).

Barrier	Strategies (Reference)
INTRA4. Lack of good governance practices	(S19) Develop good governance practices (De Filippi *et al.*, 2020). (S20) Governance strategies and rules (Lacity, 2018).
INTRA5. Lack of top-management support and supportive culture	(S21) Seek top management support (Nayak; Dhaigude, 2019; Kouhizadeh *et al.*, 2021). (S22) Disclose successful blockchain use cases (Kurpjuweit *et al.*, 2021). (S23) Keep top management actively engaged (Nayak; Dhaigude, 2019; Wong, Leong, *et al.*, 2020; Kouhizadeh *et al.*, 2021). (S24) Supporting business processes, technologies, and applications (Chen *et al.*, 2020). (S25) Promote incentive mechanisms (Tan *et al.*, 2020).
INTRA6. Internal resistance to change/adopt/use BT	(S26) Promote organisational change (Di Vaio; Varriale, 2020; Kouhizadeh *et al.*, 2021). (S27) Attract participants (Demir *et al.*, 2020). (S28) Accept and use new systems and processes (Kodym *et al.*, 2020).
INTRA7. Product type/Selection of product	(S29) Select goods with comparatively high information costs (Allen *et al.*, 2019). (S30) Select high-quality products (Abeyratne; Monfared, 2016). (S31) Select pharmacists products (Hang *et al.*, 2019; Khezr *et al.*, 2019).
INTRA8. Difficulty in choosing the right time and investment method	(S32) Carefully determine the right time to implement the technology (Kodym *et al.*, 2020).
INTRA9. Lack of experience to develop data-based business models	(S33) Training, hiring, or outsourcing (Wong; Tan, 2020). (S34) Collaborations and partnerships (Prasad *et al.*, 2018). (S35) Pilot projects and Proof of Concept (Van Hoek, 2019a). (S36) Find successful use cases (Zamani; Giaglis, 2018).
INTRA10. Complex and time-consuming process of implementation and adaptation to the new market model	(S37) Collaborate with specialised firms (Laaraj *et al.*, 2022). (S38) Focus on interoperability (Anthony Jnr, 2024).
INTRA11. Decreased operational efficiency	(S39) Using automation - NFC, RFID, Bluetooth or image recognition cameras (Sternberg *et al.*, 2021).

Source: Author's own work.

Mitigating lack of digital infrastructure and digital diffusion within the Supply Chain barrier INTRA$_1$

The company must *acquire the right experience and develop the infrastructure* to understand exactly what resources it already has and the purpose of using blockchain; the options it can choose range from training the existing team to hiring and outsourcing (Wong *et al.*, 2020a). By getting more experience and building up its digital infrastructure, the organisation can learn about its resources, train its staff, and strategically integrate blockchain, overcoming the lack of a technological basis for its adoption. *Companies should seek to understand how blockchain can augment existing processes and whether it can be adapted to the existing infrastructure*, i.e., they need to understand which type of blockchain meets the organisation's needs, such as blockchain to meet data needs; the relationship between processes and stakeholders; and how the organisation's efficiency can be improved from the use of blockchain (Wong *et al.*, 2020a). Choosing the blockchain solution that works best with the organisation makes it easier to connect with the current infrastructure, which helps with progressive digitalisation and spreads it across the SC.

Government support is required to provide the infrastructure and resources necessary to create, manage, and control the core blockchain resources, such as digital identity (Al-Jaroodi; Mohamed, 2019). The government should initiate actions to promote state-of-the-art infrastructure for SMEs (Nayak; Dhaigude, 2019), be aware of blockchain's capabilities and advantages in reducing fraud, corruption, errors, and operational costs, and aim to improve trust levels among collaborating entities (Al-Jaroodi; Mohamed, 2019). Government support for infrastructure, training, and resources helps bridge the technology gap and speeds up digitalisation along the chain. This makes it possible for firms with varied levels of digital readiness or maturity to use blockchain.

Technology readiness positively influences a company's IT adoption (Wong *et al.*, 2020a). *Scanners and Wi-Fi connections* can fully capture the data (Sternberg; Hofmann; Roeck, 2021). Technological readiness, then, sets the minimum standard for blockchain to be used and work well. Companies with adequate facilitating conditions (human resources and the right IT infrastructure) are more prepared to adopt blockchain (Wong *et al.*, 2020a).

Mitigating lack of understanding/knowledge about technology barrier INTRA$_2$

An innovative company goes beyond simply replicating a legacy system by using blockchain and associated tools, for which a good management process is crucial (Zamani; Giaglis, 2018). The innovation process is driven by *the adhesion of key members from across the organisation* and those responsible for allocating resources (financial, human, and time) (Zamani; Giaglis, 2018). This approach makes the adoption process more purposeful, informative, and strategic, turning inexperience into active and group learning.

Case studies should be carried out in real time, and findings and insights should be fed into a collaborative, shared, and transparent platform to support the improvement of blockchain adoption (Drljevic; Aranda; Stantchev, 2020). This strategy makes blockchain easier to understand and use by giving people real-world experiences and learning together. Developing human resources with the right skills, obtaining senior management support, and ensuring adherence throughout the organisation (overcoming

$INTRA_3$, $INTRA_6$, and $INTRA_7$) help people inside the company understand blockchain better, which helps them overcome technical lack of knowledge and makes it more likely that they would use it strategically.

To reap all of blockchain's benefits, users must understand its technical, practical, and governance issues (Wong *et al.*, 2020a). Organisations should *seek new talent* (Hastig; Sodhi, 2020; Wong *et al.*, 2020a; Zamani; Giaglis, 2018), combining skills in cryptography, finance, business processes, and information systems (Zamani; Giaglis, 2018). *Outsourcing* (hiring specialised companies) is also recommended (Wong *et al.*, 2020a). However, even technology developers are concerned about blockchain's lack of maturity, implementation standards, and comprehensive documentation (Themistocleous *et al.*, 2020). Given the difficulty of obtaining capable blockchain engineers and lacking external technical knowledge, *professionals must develop blockchain capabilities internally* (Kurpjuweit *et al.*, 2021). These actions together build a strong and self-sustaining base of blockchain knowledge that helps businesses make better choices, cut down on mistakes during implementation, and protect their place in the digital ecosystem.

Starting a *pilot project* can help to acquire knowledge and establish a proof of concept (Van Hoek, 2019). Provenance conducted a pilot project in Indonesia for six months in 2016, using mobiles, blockchain, and smart tagging. The pilot successfully tracked responsibly caught fish and essential social claims down the chain to export (Provenance, 2016). Other cases can be found in Kshetri (2018). Pilot projects allow organisations use blockchain on a smaller scale, which helps people learn by doing, test out ideas, and understand how the technology works in their own setting.

Efforts to improve the user experience and develop blockchain protocols are imperative (Chang; Iakovou; Shi, 2020; World Economic Forum, 2018). Kamilaris, Fonts and Prenafeta-Boldύ (2019) studied agri-food Supply Chains and identified that several startups are developing software *to make blockchain easier* for farmers to use, e.g., 1000 EcoFarms. Enhancing the user experience and creating accessible solutions aids in the comprehension and utilisation of blockchain by diverse profiles, hence surmounting technical and operational ignorance.

Themistocleous *et al.* (2020) investigated *education and training in blockchain* and proposed the structure of a master's program that can be used as a model by educational institutions. Some academic institutions offer *blockchain courses* as a postgraduate degree. This is the case of the Master's Program in Blockchain at the Moscow Institute of Physics and Technology (MIPT) in Russia, the Master's Degree in

Global Blockchain Technologies at the IL3 Universitat de Barcelona in Spain, the Master's in Global Business with Blockchain Degree of the University of the Cumberlands in the US, and a few others. Although there are some courses, there is an urgent need for adequate and practical training and development programs that can rapidly produce the necessary professional workforce in this area (Al-Jaroodi; Mohamed, 2019; Mathivathanan *et al.*, 2021; Wong *et al.*, 2020a). Academic programs and specialised trainings provide qualified specialists that help others learn more about blockchain, which speeds up its use by filling in the gaps in technical and practical knowledge.

National initiatives and government-supported education and training programs are needed (Al-Jaroodi; Mohamed, 2019; Tezel *et al.*, 2020). The government should support research and development efforts to improve and better utilise blockchain resources in different sectors by providing research grants, support for standardisation efforts, better management, and control regulations (Al-Jaroodi; Mohamed, 2019). So, the government is a catalyst for knowledge, closing the gaps in education and technology that are necessary for blockchain to be used.

Other barriers are significantly influenced by the lack of knowledge about blockchain, which is rational given that most stakeholders, particularly those in small and medium-sized enterprises (SMEs), are believed to lack a comprehensive understanding of the functionality of blockchain and its potential benefits for businesses. Blockchain is sometimes regarded to be associated with cryptocurrencies such as Bitcoin, and the volatile nature of cryptocurrencies, together with their vulnerability to value manipulation, engenders worries regarding trust and privacy (Balci; Surucu-Balci, 2021).

Mitigating lack of organisational policies/Institutional and legal norms barrier $INTRA_3$

The management of organisations must *clarify policies related to the use of* blockchain *in Supply Chain processes* (Farooque *et al.*, 2020; Saberi *et al.*, 2019; Wong *et al.*, 2020b). Clear organisational policies provide norms and responsibilities, making sure that everyone follows the law and works together to use blockchain safely and effectively in the SC. Through new policies, organisations need to *define the proper use of technology and where and when it should be used* (Kouhizadeh; Saberi; Sarkis, 2021). Policies that set rules on how to use blockchain correctly make sure that technology is used safely and effectively in the company by ensuring uniformity, compliance, and control. Manufacturers and retailers (technology users) require clear organisational policies for technologies such as blockchain; however, technology providers do not consider this a problem (Farooque *et al.*, 2020). Therefore, different entities in the Supply Chain do not usually face the same barriers; when they do, this does not happen at the same intensity.

Mitigating lack of good governance practices barrier INTRA$_4$

Companies should adopt *good governance practices* to prevent the various actors in the Supply Chain from operating in an untrustworthy manner and undermining trust in the system as a whole (De Filippi; Mannan; Reijers, 2020; Jimenez-castillo *et al.*, 2025). In liberal democratic institutions, good governance generally implies adherence to the rule of law, which consists of a clear and impartial application of existing laws and regulations unaffected by social or political considerations (De Filippi; Mannan; Reijers, 2020). Strong governance based on clear and fair standards builds confidence, coordination, and accountability among everyone in the chain, facilitating sustainable blockchain adoption.

Lacity (2018) described the *governance strategies and rules* that the companies LO3 Energy, Moog, Inc., and the Center for Supply Chain Studies are developing to face, among other challenges, the governance challenge. At LO3 Energy, a non-profit foundation was created to help local communities govern the microgrids. At Moog, Inc., the blockchain application was governed through a joint venture and a consortium for each vertical industry (e.g., aerospace, healthcare, automotive). At the Center for Supply Chain Studies, a governance sub-model that executes global rules and trading partner agreements defined by a wide range of representatives was created. Collaborative governance frameworks, including consortia and multi-stakeholder models, exemplify viable organisational strategies to ensure the sustainability and effectiveness of blockchain inside Supply Chains.

Mitigating lack of top-management support and supportive culture barrier INTRA$_5$

Top management support is essential for blockchain's adoption in the Supply Chain (Kouhizadeh; Saberi; Sarkis, 2021; Nayak; Dhaigude, 2019). Support from senior management makes sure that resources are available, encourages a positive culture, and leads integration, which is necessary to overcome objections and make blockchain adoption possible. To ensure high-level support (financial or otherwise), practitioners should find successful use cases and gain buy-in from different divisions of their organisations (Zamani; Giaglis, 2018); the *disclosure of successful use cases in blockchain* could help mitigate this barrier (Kurpjuweit *et al.*, 2021). Sharing cases of success and getting support from other departments gives senior management real proof that blockchain adoption is a good idea and helps establish a culture that supports it.

Top management *must remain actively engaged* for the desired results to be achieved (Kouhizadeh; Saberi; Sarkis, 2021; Nayak; Dhaigude, 2019; Wong *et al.*, 2020b), i.e., it must support all phases that encompass blockchain adoption and use, not just the initial phases. *Supporting business processes, technologies, and applications* is necessary, making blockchain developers important (Chen *et al.*, 2020). The involvement and engagement of logistics companies are also required, as well as the *promotion of incentive mechanisms* (Tan *et al.*, 2020).

Mitigating internal resistance to change/adopt/use blockchain *barrier* $INTRA_6$

Blockchain distributes power and reduces centralised authorities' control, so relying on a system with multiple players requires a culture change (Demir; Turetken; Mashatan, 2020). *Organisational change* is necessary, involving all the resources of the companies (human, financial, and technical) through the application of new techniques capable of generating value through the stability of the market (Di Vaio; Varriale, 2020; Kouhizadeh; Saberi; Sarkis, 2021). *Attracting participants* is also essential (Demir; Turetken; Mashatan, 2020). *New systems and processes must be accepted and used* if vital resources, such as communication and information exchange, are guaranteed (Kodym; Kubáč; Kavka, 2020). The potential benefits and wide range of blockchain applications can drive broader acceptance (Hughes *et al.*, 2019). Surmounting internal resistance to blockchain adoption requires a comprehensive cultural transformation that encompasses all organisational resources, fosters stakeholder engagement, guarantees effective communication, and emphasises the tangible advantages of the technology, thereby facilitating the transition through systematic change management processes and training to unlearn and embrace new practices.

Mitigating product type/selection of product barrier INTRA₇

It is recommended to apply blockchain to *goods with comparatively high information costs*, such as perishable goods in agriculture (Allen *et al.*, 2019; Tian, 2016), *high-quality products* (Abeyratne; Monfared, 2016), and *pharmacy products* (Hang; Choi; Kim, 2019; Khezr *et al.*, 2019). It is necessary to select products with high added value, high information costs, and products whose guarantee of origin is critical. Products with higher added value better justify the cost of technology, have greater exposure to risk and fraud, representing the best starting point for scalable adoption.

Mitigating difficulty in choosing the right time and investment method barrier INTRA₈

Carefully determining the right time to implement the technology is essential; risk management can avoid problems caused by poor implementation and threats related to the company (Kodym; Kubáč; Kavka, 2020). To prevent a premature transition, a pragmatic assessment of benefits must be conducted before any transition to blockchain; conventional architectures may provide a better and cheaper solution to add value to the business (Hughes *et al.*, 2019). Careful adoption, based on an assessment of risks and benefits, avoids premature decisions and ensures that blockchain is implemented at the right time and in the right model, maximising its strategic value.

Mitigating lack of experience to develop data-based business models barrier INTRA₉

To overcome this barrier, firms must begin to acquire this expertise. Therefore, it is imperative to initiate at a specific point. One practical approach to begin obtaining expertise is to invest in training the current team, hiring professionals, or outsourcing (Wong *et al.*, 2020a). Investing in team training, hiring specialists, or qualified outsourcing makes it possible to quickly fill the gap in internal experience, accelerating the creation of data-driven business models and enabling the strategic use of blockchain.

In addition, forming collaborations and partnerships can facilitate the exchange of knowledge and resources between companies, technology providers and competitors, thereby promoting the widespread adoption of blockchain initiatives (Prasad *et al.*, 2018). Establishing collaborations and partnerships with technology providers, companies and even competitors facilitate the sharing of knowledge and resources, accelerating collective learning and enabling the development of data-driven business models with lower risk and greater effectiveness.

Pilot Projects and PoCs can additionally facilitate the acquisition of knowledge by organisations and managers regarding developing business models based on blockchain (Van Hoek, 2019). Organisations can also learn from successful use cases other companies implement (Zamani; Giaglis, 2018). Pilot projects and PoC allow organisations to learn in practice how to structure blockchain-based business models, while observing successful cases from other companies provides concrete references and reduces uncertainty about viable implementation paths.

Mitigating complex and time-consuming process of implementation and adaptation to the new market model barrier INTRA$_{10}$

Laaraj, Nakara, Fosso Wamba (2022) discuss the role of blockchain-focused consulting companies and start-ups as change agents who can influence the growth of blockchain while removing hurdles to adoption. Consultants become true knowledge-collectors and spreaders by maintaining continuous touch with various structures, encouraging learning and skill transfer (Laaraj; Nakara; Fosso Wamba, 2022). Collaborating with companies specialised in blockchain accelerates the process of implementation and adaptation to the new market model, by bringing practical expertise, reducing technical complexity, and promoting continuous knowledge transfer between consultants and the organisation.

Anthony Jnr (2024) emphasises the necessity of enabling interoperability and integration between blockchain and legacy systems in a business, which is required for the smooth implementation of blockchain throughout the enterprise. Focusing on interoperability between blockchain and legacy systems allows for more fluid and less disruptive integration, reducing the complexity and time required to implement the technology and adapt the organisation to the new market model.

Mitigating decreased operational efficiency barrier INTRA$_{11}$

This barrier could be addressed with *automation*, using *near-field communication (NFC), radio frequency identification (RFID), Bluetooth, or image recognition cameras* (Sternberg; Hofmann; Roeck, 2021). However, this requires substantial changes in the hardware and software IT infrastructure, including the enterprise resources planning (ERP) systems, which is also a barrier for companies (Sternberg; Hofmann; Roeck, 2021). Automation using these technologies optimises logistics and monitoring processes, reducing errors and delays, which increases operational efficiency and minimises the negative impact of blockchain adoption on operations. Therefore, this barrier can be mitigated when companies develop an adequate IT infrastructure (overcoming INTRA1).

5.4.2.3 Mitigating cost-related barriers

The literature presents mitigation strategies for all cost-related barriers. Table 5.7 summarises these results.

While our study exclusively examines non-technical hurdles to blockchain adoption, the interrelationship between technological and non-technology barriers is a critical consideration. Many barriers, categorised as non-technological, originate from technical concerns, making harder the differentiation between these two categories of barriers. In many cases, technological barriers can be surmounted if there are no financial constraints. In the absence of financial limitations, numerous technological barriers can be surmounted through investments in research and innovation, ultimately yielding more cost-effective and efficient solutions.

Likewise, the accessibility of financial resources is essential for addressing non-technological barriers. Staff training and the redesign of administrative processes are effective strategies, if there is sufficient financial support that can mitigate the adverse effects of barriers first deemed unconnected to technical concerns. While our study addresses technological and non-technological barriers independently, it is crucial to acknowledge their interdependence, as surmounting one frequently relies on overcoming of the other.

Table 5.7 - Strategies to mitigate cost-related barriers

Barrier	Strategies (Reference)
COST1. Lack of a clear return on investment/financial attractiveness	(S1) Develop a new business model for blockchain service with less cost and less risk (Wan *et al.*, 2020). (S2) Seek business case indicating expected returns (Kurpjuweit *et al.*, 2021).
COST2. High cost of implementation/Financial Constraints	(S3) Assess the marginal costs (De Giovanni, 2020). (S4) Promote coopetition among competitors (Gausdal *et al.*, 2018). (S5) Encourage the union of government and the private sector (Ching-Fu, 2019; Yadav *et al.*, 2020). (S6) Minimum Viable Product (MVP) or Proof of Concept (PoC) (Mundra, 2018). (S7) Cloud-based blockchain implementations (Patrizio, 2018; Morkunas *et al.*, 2019).
COST3. High sustainability costs	(S8) Promote the use of green and renewable energies (Attaran; Gunasekaran, 2019; Kouhizadeh *et al.*, 2019; Vilkov & Tian, 2019; Ahl *et al.*, 2020; Di

Barrier	Strategies (Reference)
	Vaio & Varriale, 2020). (S9) Mitigate scalability issues (Biswas; Gupta, 2019). (S10) Proof of Stake (PoS) schemes (Mendling *et al.*, 2018; Andoni *et al.*, 2019; Khan *et al.*, 2020). (S11) Private blockchains (Prasad *et al.*, 2018; Cole *et al.*, 2019). (S12) "Sharding" (Panarello *et al.*, 2018; Andoni *et al.*, 2019; Vinay Reddy, 2019). (S13) Neighborhood micro-grids (Attaran; Gunasekaran, 2019).
COST4. High Usage costs	(S14) Adopt centralisation (Pirrong, 2019). (S15) Use sidechains (Andoni *et al.*, 2019). (S16) Operate the blockchain as a control layer, no longer as a storage layer (Andoni *et al.*, 2019). (S17) Different consensus algorithms (Zhao *et al.*, 2019; Andoni *et al.*, 2019). (S18) Consortium blockchain (Jiang *et al.*, 2019).
COST5. Poor economic behavior in the long run and the lack of a fully formed blockchain market	(S19) Introduce new legislation (Karapetyan *et al.*, 2019).

Source: Author's own work.

Mitigating lack of a clear return on investment/financial attractiveness barrier $COST_1$

Many companies are unwilling to take risks and make blockchain investments without knowing the return they can achieve. Many believe the current information-sharing system is working well, so blockchain is unnecessary (Wan; Huang; Holtskog, 2020). It is necessary to *develop a new business model for blockchain services with less cost and less risk* (Wan; Huang; Holtskog, 2020). Developing business models for blockchain services that minimise costs and risks makes investments more attractive, facilitating a clear perception of financial returns and encouraging the adoption of technology.

Blockchain adoption depends on top managers' financial investment decisions due to the associated risks and uncertainties, volatility, and environmental conditions (Kurpjuweit *et al.*, 2021). Top managers need a *business case that indicates the expected returns* (Kurpjuweit *et al.*, 2021). Cases like these facilitate safer investment decisions aligned with strategic objectives. $COST_1$ highlights the importance of senior management support and the dissemination of successful blockchain use cases, indicating financial benefits and returns.

Mitigating high cost of implementation/financial constraints barrier $COST_2$

Companies may find blockchain implementation and its business implications economically inconvenient; however, companies can adjust their strategies to recoup the investment in the fixed cost of implementation (De Giovanni, 2020). Blockchain's marginal costs and the tokens significantly impact the business, making the marginal costs more critical. Therefore, companies must first *assess the marginal costs*; if these are high, blockchain should not be implemented, as its adoption cannot be justified (De Giovanni, 2020). By carefully assessing marginal costs before implementation, companies can adjust their strategies to recoup investments and avoid financially unviable adoptions, ensuring that blockchain use is economically sustainable and aligned with the organisation's financial capabilities.

Coopetition can be adopted to share risks and costs among competitors, as observed by Gausdal, Czachorowski and Solesvik (2018) in the maritime industry. The adoption of coopetition allows competing companies to share the risks and costs of implementing blockchain, reducing the individual financial burden and enabling investments that would be unfeasible in isolation. Another recommendation is for the *union of the government and the private sector* to support this initiative for the benefit of the masses (Ching-Fu, 2019; Yadav *et al.*, 2020). Government-private partnerships can alleviate the high costs of implementing blockchain by providing resources, financial incentives, and shared infrastructure, making adoption more accessible and viable for businesses.

The least risky way would be to start with a *minimum viable product (MVP) or proof of concept (PoC)* (Mundra, 2018). In 2016, IBM and Maersk conducted a PoC to track a container of flowers from the Kenyan coastal city of Mombasa to Rotterdam in the Netherlands (Kshetri, 2018). In this PoC, the shipping cost was $2,000, and the paperwork was estimated at $300 (15% of the cargo's value); the PoC was considered a success (Kshetri, 2018). Starting with an MVP or PoC makes it possible to test the viability of blockchain at reduced costs, demonstrate concrete benefits, and obtain practical learnings that justify larger investments, while minimising financial risks associated with large-scale implementation.

Companies such as Amazon, IBM, and Microsoft offer *cloud-based blockchain implementations* and models at a lower cost than specialised development (Morkunas; Paschen; Boon, 2019; Patrizio, 2018). These models facilitate the configuration process, reduce implementation time from months to days, and allow organisations to reduce the costs of these initiatives (Morkunas; Paschen; Boon, 2019). Therefore, organisations can significantly reduce costs and implementation time, making technology adoption more accessible and financially viable.

Expensive infrastructure costs must be offset by the benefits gained from enhanced data integrity, improved security, the lack of the need for a trusted intermediary (Andoni *et al.*, 2019), simplified operations, reduced risks, and reduced compliance costs (Ko; Lee; Ryu, 2018; Kumar; Liu; Shan, 2020; Demir; Turetken; Mashatan, 2020). First, the return on investment (ROI) must be examined because the blockchain must pay for itself; otherwise, it is not worth implementing (Mundra, 2018; Prasad *et al.*, 2018). Accordingly, dealing with $COST_1$ can help at this point.

Not investing in blockchain is the same as not investing in projects that generate positive net present value (NPV) because of concerns about short-term gains, and this can be harmful in the long term (Ko; Lee; Ryu, 2018). As more application experience is gained, the deployment cost issue can be devalued and reduced (Mackey *et al.*, 2019; Makridakis, 2019).

Mitigating high sustainability costs barrier $COST_3$

Companies should opt for *green and renewable energy sources* (Ahl *et al.*, 2020; Attaran; Gunasekaran, 2019; Di Vaio; Varriale, 2020; Kouhizadeh; Sarkis; Zhu, 2019; Vilkov; Tian, 2019). Opting for green and renewable energy sources reduces the environmental and financial costs associated with operating the blockchain, making the technology more sustainable and aligned with the socio-environmental responsibility demands of Supply Chains. This barrier can also be controlled when *scalability issues are mitigated* (Biswas; Gupta, 2019). To achieve the efficiency of mining and proof-of-work (PoW), reducing the number of wasted resources is important (Yli-Huumo *et al.*, 2016).

Instead of using PoW, which is highly energy-intensive, blockchain needs energy-efficient consensus mechanisms (Jawaji *et al.*, 2020), e.g., *proof-of-stake (PoS) schemes* that are energy-efficient, faster, and more scalable (Andoni *et al.*, 2019; Mendling *et al.*, 2018). To avoid the wastage of computing resources (hardware and electricity), costs can be eliminated by using PoS techniques (Khan *et al.*, 2020). This strategy significantly reduces the energy consumption and operational costs of the blockchain, making its implementation more sustainable and economically viable. The energy consumption of *private blockchains* is lower than that of public blockchains (Prasad *et al.*, 2018; Cole; Stevenson; Aitken, 2019).

The *sharding* approach allows the system to process information in parallel, improving scalability (Ahl *et al.*, 2020; Andoni *et al.*, 2019; Meyer; Kuhn; Hartmann, 2019; Panarello *et al.*, 2018; Vinay Reddy, 2019; Yu; Liang; Xu, 2019). Zilliqa, a blockchain platform designed to scale transaction rates, employs the idea of sharding, i.e., transforming the mining network into smaller shards, each capable of processing transactions in parallel (The ZILLIQA Team, 2017). The sharding technique improves blockchain scalability by dividing the network into smaller parts that process transactions in parallel, reducing energy consumption per transaction and, consequently, the environmental costs associated with operating the technology. Another option is *neighbourhood micro-grids*, i.e., neighbours with the capacity to produce, consume, and buy smaller amounts of energy within their community, as observed in the company LO3 Energy regarding the use of renewable energy (Attaran; Gunasekaran, 2019). The LO3 Energy case shows how the use of local microgrids with shared generation and consumption of renewable energy reduces dependence on carbon-intensive sources and energy operating costs, making the application of blockchain more sustainable and financially accessible.

Mitigating high usage costs barrier $COST_4$

Centralisation is recommended, which reduces the costs of finding a counterparty; however, this would violate the principle of a fully decentralised mechanism proposed by blockchain (Pirrong, 2019). Using *sidechains* and operating blockchain as a *control layer* (instead of a storage layer) can reduce the cost of data storage (Andoni *et al.*, 2019). By utilising sidechains and operating the blockchain as a control layer rather than storage, companies significantly reduce usage costs, especially with data, making the technology lighter, more efficient, and affordable.

De Giovanni (2020) made the following recommendations regarding marginal costs: a) when the marginal costs are high, blockchain should not be implemented, as the number of tokens, the risks, and the mitigation of the transaction cost will not justify its adoption; b) if marginal costs are affordable, all Supply Chain members can do better economically by removing business risks and transaction costs; c) increasing the number of tokens provides more economic advantages; and d) even following these recommendations, companies need a careful analysis of the risks of implementing blockchain.

The literature proposes *different consensus algorithms*, e.g., PoS, the delegated PoS algorithm, or proof-of-authority, which can reduce computation time (Andoni *et al.*, 2019; Zhao *et al.*, 2019). The adoption of more efficient consensus algorithms, such as these, reduces the time and computational resources required to validate transactions, significantly reducing the costs of using the blockchain. To reduce the high cost of collaboration for many agents, it is possible to use a *consortium blockchain* as a control station through smart contracts (Jiang *et al.*, 2019). Jiang *et al.* (2019) presented an access control model in which only members of the consortium network can access data records through access requests. Hyperledger is another example of a consortium blockchain (Feng *et al.*, 2019; Lu *et al.*, 2019).

Mitigating poor economic behavior in the long run and the lack of a fully formed blockchain market barrier $COST_5$

The lack of a fully formed blockchain market brings much uncertainty, so companies do not know if there will be a demand for their products and services. However, with the *introduction of new legislation*, it will be possible to improve the quality of blockchain projects, and their ability to compete in the market will increase (Karapetyan *et al.*, 2019). The introduction of new legislation tends to better structure the blockchain market, reducing regulatory uncertainties, encouraging investor confidence, and increasing the competitiveness and economic sustainability of projects in the long term.

5.5 Discussion - The Role of Stakeholders in Developing Strategies to Mitigate Blockchain Adoption Barriers in Supply Chains

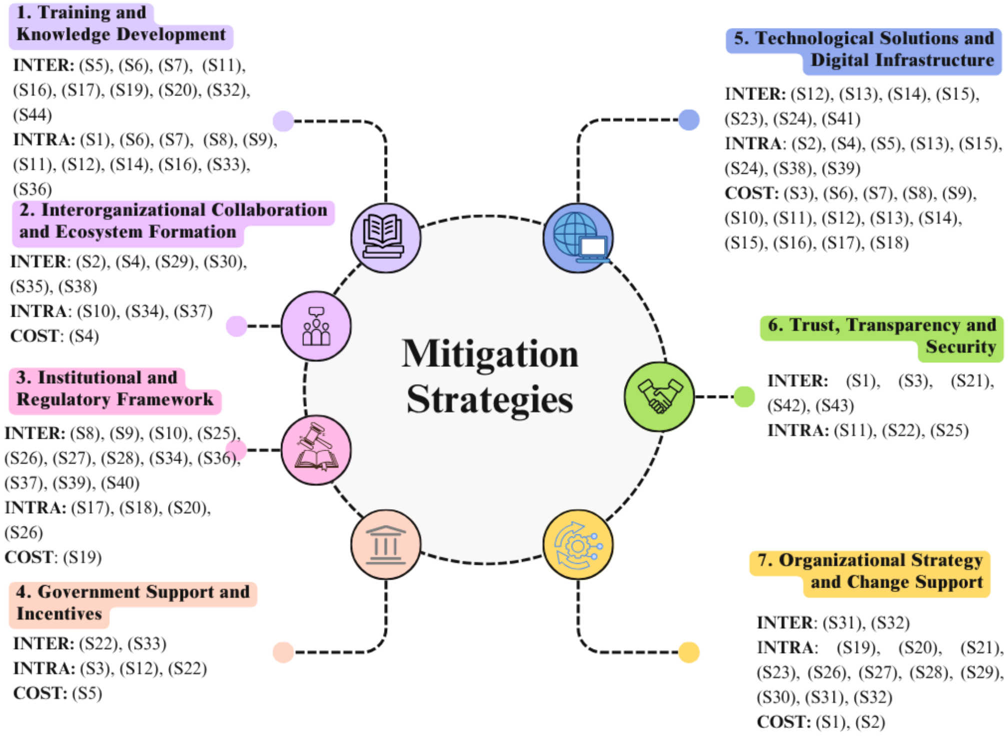
The blockchain research topic is nascent, and Supply Chains face many barriers to its adoption. Although barriers have been discussed in several blockchain studies, they have aimed to list the existing barriers but have not addressed the means of dealing with them in depth. In this article, we have identified the non-technological barriers faced by Supply Chains in adopting/using blockchain and the strategies to mitigate them through a comprehensive SLR.

Three categories of non-technological barriers were identified, with 13 items in the inter-organisational barriers category, 11 in the intra-organisational barriers category, and five in the cost-related barriers category. In the first category, the incompleteness of legal regulations was the most mentioned barrier; in the second category, the lack of human/professional knowledge about technology; and in the cost-related category, the high cost of implementation and financial constraints.

There are barriers that, when eliminated or minimised, culminate in mitigating others. One such example is the intra-organisational barrier, "lack of understanding of how to manage the technology", which can be minimised through the mitigation of the barriers "lack of human/professional knowledge about technology", "lack of top management support", and "internal resistance and corporate culture". Thus, we suggest that future studies analyse the influence relationship between barriers to prioritise the most influential barriers, work on strategies to mitigate them, and understand other barriers influenced by them.

The sooner these barriers are investigated, the better the implementation and use of blockchain will be. Since the identified barriers are general (Supply Chains in general), companies should seek to understand the context in which their business is inserted and the implications of each barrier to define the barriers that affect them. We suggest that the strategies for mitigating the barriers provided in this study be further analysed and that technology implementation teams develop an action plan or risk management plan to deal with the barriers according to their business context. Figure 5.4 presents the mitigation strategies grouped into meta-categories, these categories aim to capture the main focuses of the mitigation strategies.

Figure 5.4 - Strategic grouping of key mitigation strategies



Source: Author’s own work.

The meta-categories were defined based on the identification and grouping of key themes and dimensions present in the mitigation strategies, considering their objectives and contexts of application. The mitigation strategies identified in the literature were organised into seven analytical meta-categories that reflect the main strategic dimensions involved in overcoming barriers to blockchain adoption in Supply Chains, namely: Training and Knowledge Development, Interorganisational Collaboration and Ecosystem Formation, Institutional and Regulatory Framework, Government Support and Incentives, Technological Solutions and Digital Infrastructure, Trust, Transparency and Security, and Organisational Strategy and Change Support.

The first, *training and knowledge development*, encompasses initiatives aimed at building technical and managerial skills, disseminating best practices, and promoting organisational learning. The second, *inter-organisational collaboration and ecosystem formation*, refers to cooperative efforts such as partnerships between companies and sectors, consortia, joint testing, and other coordinated actions to enable the broad implementation of blockchain solutions. The third, *institutional and regulatory framework*, includes actions focused on the creation, adaptation, or enforcement of legal frameworks, public policies, standards, and institutional mechanisms that ensure the secure and legitimate use of the technology.

The fourth category, *government support and incentives*, comprises direct involvement from public authorities, including subsidies, regulatory support, public education initiatives, and other forms of institutional encouragement. The fifth, *technological solutions and digital infrastructure*, involves the application or improvement of technical tools to address challenges related to interoperability, scalability, cybersecurity, and the development of viable technological alternatives. The sixth category, *trust, transparency, and security*, includes actions designed to mitigate stakeholder distrust, ensure the integrity of data, and build systems that are reliable and auditable. Finally, the seventh category, *organisational strategy and change support*, covers the internal enablers of adoption, such as leadership engagement, organisational culture, and change management practices that foster an environment conducive to technological transformation.

Another crucial aspect in mitigating non-technological barriers for blockchain adoption in the Supply Chain is the role of the stakeholders in such effort. The role of some key stakeholders can be determined by examining the strategies to mitigate inter-organisational barriers. Focusing specifically on inter-organisational barriers, Supply Chain partners can develop partnerships with digital platform companies to increase customer convenience and engagement (Ahl *et al.*, 2020). In this way, big digital firms like Google, Amazon, and Microsoft, as well as startups, may work together to develop platforms and solutions that will make blockchain easier to implement and use. Additionally, to increase blockchain 's public acceptability and trust, consumers and businesses should embrace and spread interesting use cases of the application of this technology.

The participation of technology providers is crucial in assisting Supply Chain partners with developing the infrastructure required for blockchain implementation (Wong *et al.*, 2020a). Regulatory bodies play a vital role in establishing policies and laws that specify which types of information must be disclosed. This aids blockchain 's integration into Supply Chain Management (Galvez; Mejuto; Simal-Gandara, 2018; Nayak; Dhaigude, 2019). Government support can be extended through intellectual property protection, rules and guidelines for blockchain use, taxation metrics, and punishment for fraudulent activity (Sydow; Sunny; Coffman, 2020). Furthermore, based on our research's findings, it can be concluded that the media can also be very helpful in attempting to dispel the myth that blockchain is associated with illegal activity. This can be achieved by promoting attributes like transparency and ethical use of this technology, as well as by educating the public about its true advantages and capabilities.

Considering the crucial role these stakeholders play in overcoming the inter-organisational barriers identified in our study, we introduce our study's initial proposition. The propositions developed aim to improve our understanding of the dynamics involved in technology adoption by reflecting on the role and interactions of stakeholders in the process of overcoming these barriers. It highlights the necessity for enhanced collaboration and coordination among external stakeholders to effectively address challenges such as trust deficits, regulatory uncertainties, and the complexities inherent in integrating Supply Chains.

Proposition 1: Addressing inter-organisational barriers to blockchain adoption requires the active participation of external stakeholders such as Supply Chain partners, industry consortia, regulatory bodies, and technology providers. Collaborative efforts focused on standardisation, regulatory clarity, and trust-building initiatives are essential for creating a conducive environment for blockchain integration across organisational boundaries.

Concerning the role of stakeholders in mitigating the intra-organisational barriers, developing effective governance strategies and regulations requires the support of top management (De Filippi; Mannan; Reijers, 2020; Lacity, 2018). Senior management's continuing encouragement is essential to the long-term viability of blockchain adoption. This includes ensuring financial support and obtaining a commitment from various organisational divisions (Zamani; Giaglis, 2018). The active participation of IT managers is critical due to the positive correlation between the technological readiness of an organisation and its propensity to adopt new technologies (Wong *et al.*, 2020a).

IT teams and blockchain experts must cultivate internal competencies and execute pilot projects to acquire technical knowledge regarding the technology. Companies must prioritise investing in team training and, when necessary, engage specialised firms to facilitate this training. Alongside educating current teams, measures to alleviate intra-organisational barriers have involved employing specialists or outsourcing tasks. Personnel should try to acquire additional competencies to enhance their adoption and utilisation of the novel systems and procedures associated with the blockchain implementation (Kodym; Kubáč; Kavka, 2020; Zamani; Giaglis, 2018). The organisation is better positioned to incorporate blockchain into its operations if it possesses the appropriate IT infrastructure and human resources (Wong *et al.*, 2020a).

Based on this, we have our second proposition. This proposition emphasises the need for a cohesive internal approach, highlighting the roles of various internal stakeholders in overcoming barriers related to knowledge, infrastructure, and organisational culture.

Proposition 2: To effectively mitigate intra-organisational barriers to blockchain adoption in Supply Chains, it is crucial to involve a broad spectrum of internal stakeholders, including top management, IT professionals, and operational staff. Engaging these stakeholders in the development and execution of tailored educational programs, infrastructure enhancements, and cultural change initiatives will ensure the necessary organisational readiness and support for blockchain.

Regarding the cost-related barriers, the participation of technology providers, particularly blockchain solution providers, is crucial in advancing the development of a novel business model for blockchain services with lower costs and risks (Wan; Huang; Holtskog, 2020). An illustration of this is exploring cloud-based blockchain solutions (Morkunas; Paschen; Boon, 2019). The government and private sector collaborating to support blockchain initiatives for the benefit of the masses (Ching-Fu, 2019; Yadav *et al.*, 2020) to surmount cost-related barriers is an additional crucial partnership. The government can implement legislation and regulations that enhance confidence in blockchain, to reduce uncertainty associated with this technology. Monetary authorities and banks must also collaborate to establish a robust infrastructure supporting global transactions (Zhang; Jia; Chen, 2024).

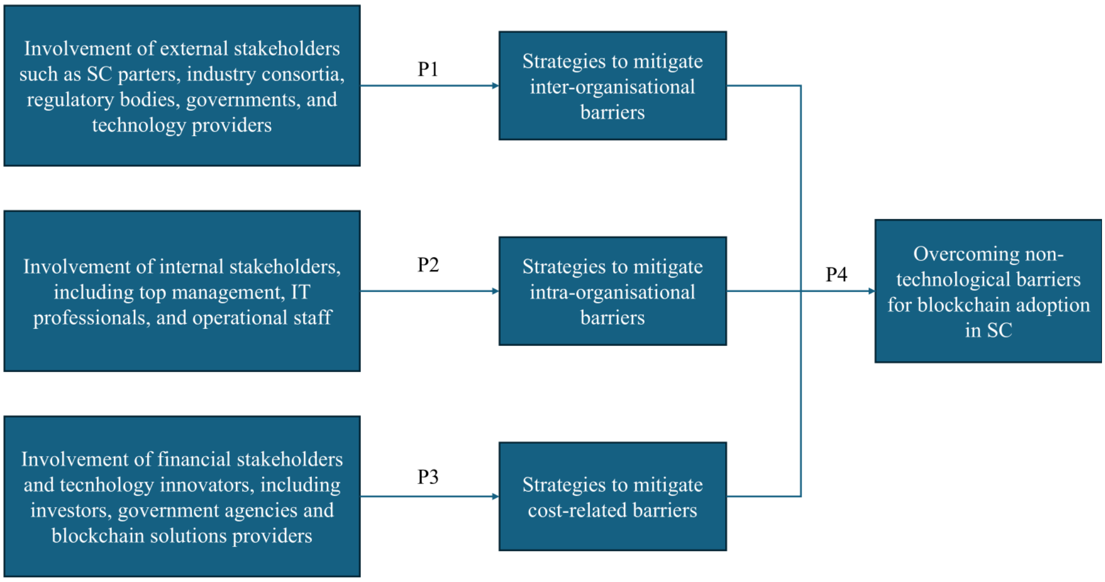
Based on these considerations, we have our third proposition. It identifies financial and technological stakeholders as key to addressing the high implementation and operation costs, emphasising the need for innovative funding models and efficient technologies to reduce financial barriers.

Proposition 3: Overcoming cost-related barriers to blockchain adoption requires engagement from financial stakeholders and technology innovators, including investors, government agencies, and blockchain solution providers. Strategic investment in cost-efficient blockchain models, leveraging governmental incentives, and adopting scalable and energy-efficient technologies are critical steps that require stakeholder collaboration to ensure economic viability and sustainability.

Finally, our research findings substantiate the assertion that navigating non-technological barriers to blockchain adoption necessitates a comprehensive approach, encompassing strategies that mitigate inter-organisational, intra-organisational, and cost-related domains. This achievement is feasible through the engagement of a diverse array of stakeholders, as outlined in Propositions 1, 2, and 3. Echoing the insights of (Zhang; Jia; Chen, 2024), who argue that stakeholder collaboration presents a significant challenge to blockchain implementation, we maintain that each stakeholder plays a critical role in surmounting the obstacles impeding blockchain integration within Supply Chains. This premise lays the groundwork for our fourth proposition.

Proposition 4: The integrated adoption of strategies aimed at mitigating intra-organisational, inter-organisational, and cost-related barriers is crucial for overcoming the non-technological barriers faced in implementing blockchain within Supply Chains. To ensure an effective and sustainable transition to blockchains, key stakeholders specific to each barrier group must be actively involved.

Figure 5.5 - Involvement of SC stakeholders in mitigating non-technological barriers



Source: Author's own work.

5.6 Conclusion

This section concludes the study by synthesising its main findings and discussing their implications for both theory and practice. It also presents the final remarks and outlines the key limitations of the research, highlighting opportunities for future studies on blockchain adoption in supply chains.

5.6.1 Implications for Theory and Practice

This study has both theoretical and practical implications. Our research advances the blockchain adoption discourse by unveiling the non-technological barriers within Supply Chains and proposing a structured approach to mitigate these barriers. Our systematic literature review (SLR) delineates three primary categories of non-technological barriers: inter-organisational, intra-organisational, and cost-related, each presenting unique challenges to blockchain adoption. The identification of these categories and their specific items contributes to the theoretical foundation by offering a comprehensive framework that categorises barriers beyond the technological perspective. Moreover, our propositions introduce a novel theoretical perspective by emphasising the interconnectedness of these barriers and suggesting that mitigating certain barriers could inherently diminish others. This insight encourages future research to explore the dynamic interplay between different categories of barriers and their cumulative impact on blockchain adoption in Supply Chains.

In terms of practical implications, this research provides several insights related to blockchain in Supply Chain Management. Decision-makers can benefit from this study; they can use the insights to make more informed decisions about whether and how to adopt blockchain. For example, they can employ the proposed categories as a checklist of non-technological barriers and strategies to overcome them. Understanding non-technological barriers allows them to anticipate challenges and develop strategies to address them proactively. Moreover, decision makers can incorporate strategies to overcome barriers into their strategy planning to help embrace and integrate blockchain more smoothly into their operations. This information can help managers effectively mitigate the risks linked to implementing blockchain.

Additionaly, our study incentives collaboration and effective communication among Supply Chain stakeholders. External stakeholders such as Supply Chain partners, industry consortia, regulatory bodies, and technology providers are central to overcoming inter-organisational barriers. Their collaborative efforts are crucial for establishing the standards and trust necessary to navigate the regulatory uncertainties and align diverse organisational practices. Internally, the engagement of stakeholders within an organisation, including top management, IT professionals, and operational staff, is essential. Their commitment and proactive approach in addressing the intra-organisational barriers can significantly enhance the understanding and management of blockchain. This involves cultivating a supportive culture, investing in technological readiness, and developing human capital tailored to the intricacies of blockchain. When it comes to cost-related barriers, financial stakeholders play a pivotal role. The participation of investors, government agencies, and blockchain solution providers can drive the innovation necessary to develop cost-effective blockchain solutions. Their involvement is key to the creation of novel business models and funding mechanisms that reduce the economic impact of blockchain adoption and operation.

5.6.2 Final Remarks and Limitations

This study contributes to the literature by surveying and organising all non-technological barriers related to blockchain adoption in the Supply Chain and how companies can deal with them. We analysed 155 articles that used different methods and focused on various application areas, revealing essential Supply Chain Management insights. Despite the increasing number of publications over the years, the predominance of theoretical-conceptual studies highlights the lack of empirical maturity regarding blockchain use in Supply Chains.

The study has some limitations. First, technological barriers were not addressed, as these deserve a separate and in-depth analysis. It was not possible to exhaustively explore the strategies of mitigating the barriers. Future studies may immerse themselves in a specific barrier, or small groups, to carry out a deeper analysis and address this gap. We also identified an influence relationship between the barriers; thus, we suggest that studies be carried out to investigate these relationships. Despite these limitations, we believe that the list of barriers and strategies to mitigate them are valuable results that will improve the decision-making process during the phases of blockchain adoption in the SC.

6 A DESIGN SCIENCE FRAMEWORK FOR READINESS MODEL DEVELOPMENT IN DIGITAL OPERATIONS AND SUPPLY CHAIN MANAGEMENT (Paper 3)

This chapter addresses the methodological problem of how readiness models for emerging digital technologies should be designed and structured in operations and supply chain management. Drawing on Design Science Research principles, the study develops and validates a reference architecture that outlines essential components and development steps for readiness model design.

6.1 Introduction

Digital technologies, particularly those associated with Industry 4.0 (I4.0), are increasingly important for businesses and offer significant benefits to Operations and Supply Chain Management (OSCM), notably by enabling data-driven, interconnected and automated operations that can improve supply chain performance and sustainability (Pervez *et al.*, 2026). Industry 4.0 technologies encompass both foundational technologies, such as the Internet of Things (IoT), cloud computing, big data, and analytics, and so-called front-end technologies, such as smart working, Smart Manufacturing, Smart Products, Smart Supply Chain and Smart Working (Frank; Dalenogare; Ayala, 2019). More recently, the discussion has expanded toward Industry 5.0, which complements Industry 4.0 by shifting attention beyond technology-driven performance toward human-centric, resilient, and sustainable production and logistics systems (Grosse *et al.*, 2023). These technologies enable organizations to leverage digitized data for process optimization and present novel prospects for generating customer value (de Vass; Shee; Miah, 2018; Eslami *et al.*, 2021).

Companies face many challenges in fully embracing Industry 4.0 and digitalization, aiming to maximize their benefits. Key obstacles include substantial investments, difficulties integrating value chains, the nascent stage of preferred technologies, and an aversion to change (Raj *et al.*, 2020). These barriers contribute to the complexity of adopting I4.0 technologies. The theory of Organizational Readiness for Change (ORC) suggests that a higher degree of preparedness within an organization increases the chances of successful innovation adoption and minimizes the risk of failure (Jöhnk; Weißert; Wyrtki, 2021; Snyder, 2001; Weiner, 2009). However, fostering a unified readiness mindset is a formidable task, leading many companies to struggle with establishing sufficient organizational readiness. As a result, they encounter significant challenges or outright failure in executing complex organizational transformations (Weiner, 2009).

Before adopting new technologies, organizations must assess their current readiness using an appropriate methodology that encompasses all essential prerequisites for initiating the transformative journey. This involves leveraging readiness models (RMs), which delineate various levels and dimensions of readiness, acting as benchmarks for gauging progress toward achieving transformation readiness (Tripathi; Gupta, 2021). Such a systematic approach to readiness assessment can help organizations avoid the pitfalls of incurring high costs and perceiving significant risks associated with the implementation of digital innovations, which often come with uncertain future returns (Trstenjak *et al.*, 2022). Therefore, a thorough understanding of the organization's existing readiness level is paramount in crafting an effective strategy for transformation (Tripathi; Gupta, 2021). Conducting a readiness assessment before implementing planned changes provides organizations with a valuable opportunity to identify and address any shortcomings within their current context, smoothing the path for successful organizational change (Holt *et al.*, 2007; Pirola; Cimini; Pinto, 2020). This strategic approach complements the earlier emphasis on the importance of Organizational Readiness for Change in enhancing the likelihood of successful technology adoption and minimizing failure risks by ensuring that companies are not only ready to embrace change but are also strategically prepared to navigate the complexities of Industry 4.0 and digitalization.

This diversity and lack of coherence among Readiness Models highlight a critical gap in the literature and practice, underscoring the need for a standardized approach to assess and enhance readiness for emerging digital technologies in organizations. Against this backdrop, our research seeks to delve into the intricacies of Readiness Models within the context of Operations and Supply Chain Management, aiming to unravel the key components that constitute effective Readiness Model for adopting digital innovations. Therefore, our investigation is driven by the following research question (RQ):

RQ$_7$: What are the essential components and methodological steps for designing Readiness Models that support the adoption of emerging digital technologies in Operations and Supply Chain Management, and how can these be integrated into a reference architecture?

By exploring this RQ, we aim to offer a unified framework that consolidates the essential elements of Readiness Models, thereby furnishing organizations with a clear and comprehensive roadmap for evaluating and enhancing their preparedness for digital innovation adoption. This initiative aims to fill a notable gap in existing research and provide actionable guidance for entities grappling with the intricacies of digital transformation in the Industry 4.0 landscape. While not a direct readiness assessment tool, the proposed framework is essential for shaping models dedicated to this end. It promises to inject structured methodology, analytical rigor, and adaptability into the design of Readiness Models tailored explicitly for the Operations and Supply Chain Management field, delivering value to both practitioners and scholars.

The paper is organized into 7 sections. Section 6.2 describes the theoretical background. Section 6.3 presents the research methodology. Section 6.4 presents the results and discussion related to the reviewed studies in SLR, the proposal, and the refinement and validation of the framework. Section 6.5 presents an ex-ante evaluation through a conceptual simulation, illustrating the practical application of the framework. Section 6.6 discusses the main results and theoretical and managerial implications, while Section 6.7 summarizes the conclusions and research limitations.

6.2 Theoretical background

This section presents the theoretical background supporting this study, focusing on the distinction between readiness and maturity in digital innovation and the foundations for designing readiness assessment frameworks. It integrates perspectives from Diffusion of Innovations (DOI) theory and Design Science Research (DSR).

6.2.1 Diffusion of Innovations Theory (DOI) and the difference between Readiness Model and Maturity Models within the Industry 4.0 domain

It is crucial to emphasize the specific definition of readiness that we are employing in this study. Despite differences in their definitions, "maturity models" and "readiness models" are frequently employed interchangeably or synonymously in existing literature (Pirola; Cimini; Pinto, 2020; Saad; Bahadori; Jafarnejad, 2021). We have identified papers that classify their models as readiness assessment models (e.g., Gürdür; El-khoury;

Törngren, 2019). However, most of these models are Maturity Models, as also observed by (Basl, 2017).

The topic of maturity is extensively examined in academic literature, and numerous models exist for evaluating organizations' maturity level about I4.0 and digital innovation. More recently, the discussion has expanded toward Industry 5.0, which complements Industry 4.0 by shifting attention beyond technology-driven performance toward human-centric, resilient, and sustainable production and logistics systems (Grosse *et al.*, 2023). Nevertheless, innumerable technologies associated with digital innovation and Industry 4.0 and 5.0 (I4.0/I5.0) remain in their infancy in business; in fact, most organizations are still quite young in their engagement with these technologies. Consequently, before addressing maturity assessment, it is crucial to understand pre-maturity concerns, namely the readiness of organizations to adopt such technologies. The significance of the readiness topic is inherently apparent, given the ongoing evolution of I4.0 and digital innovations, which has resulted in numerous organizations yet to embark on their digital transformation (Felippes *et al.*, 2022). In their study, Felippes *et al.* (2022), consider that readiness is related to how ready the company is to enter the I4.0 trajectory, while maturity is associated with the notion that the company is already mature, at some level, for the I4.0.

According to Antony, Sony and McDermott (2023), "organizations use Industry 4.0 readiness models to evaluate their preparedness before implementing Industry 4.0." Noting the term "prior preparedness" is crucial, as it indicates that readiness must be evaluated before initiating any change implementation. According to Pacchini *et al.*, (2019), readiness is defined as the "state in which an organization is ready to accomplish a task" while maturity is defined as "the level of evolution that an organization has accomplished concerning a task."

According to Lokuge *et al.* (2019), readiness is a continuum, a "degree" or a "level" of preparation rather than a dichotomy of "being ready" or "not being ready." That is why the instrument is important for assessing this latent level of readiness. Since Lokuge *et al.* (2019) definition best fits our proposal, we shall employ it in this study. A readiness assessment model is critical for any firm considering using a new technology. Maturity and readiness assess distinct aspects at various stages during the life cycle of an innovation within an organization.

The focus audience, or unit of analysis, of a Readiness Model differs from that of a maturity model. Because the term "readiness" induces a tendency for change in a given system (Alcácer *et al.*, 2021), it can be stated that the so-called "potential users" will benefit from this instrument. These companies intend to implement a change and have already determined that the technology is suitable and can add value to their processes. A Readiness Model is a tool that is used to predict the future, as defined by (Botha, 2018). Hence, the objective of a readiness assessment is to discern potential hazards, advantageous circumstances, and obstacles that could emerge during the practical implementation of change initiatives within an organization (Pirola; Cimini; Pinto, 2020). In maturity models, we analyze the "current users" of a given innovation: firms that have already embraced or begun implementing it and want to improve their practices with this technology. While the term readiness refers to preparation for initial implementation, maturity refers to advancement after development (Akdil; Ustundag; Cevikcan, 2018; Botha, 2018; Monshizadeh *et al.*, 2023).

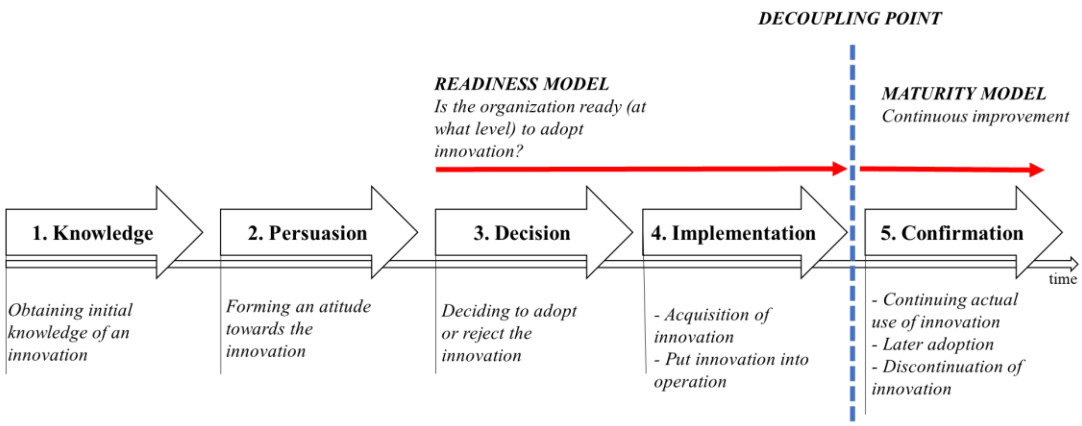
This allows us to discern between readiness and maturity regarding an innovation's life cycle. The DOI theory was proposed by (Rogers, 2003), and addresses aspects related to the diffusion and adoption process of an innovation. We are studying innovations involving digital technology, or digital innovations as we refer to them here. The DOI theory has been applied in several studies to analyze how digital innovations are adopted (Hameed; Counsell; Swift, 2012; Nath *et al.*, 2022; Rauniyar *et al.*, 2023). This theory states that novelty and degree of uncertainty are what set innovative decision-making apart from other forms of decision-making. Therefore, the process of determining whether to embrace a technology is inextricably tied to the need to handle uncertainty. As such, the decision to use a technology shouldn't be made immediately. Instead, it is a gradual process that involves several distinct steps.

The DOI theory posits that the innovation-decision process comprises five distinct stages: Knowledge, Persuasion, Decision, Implementation, and Confirmation (Rogers, 2003). The knowledge stage is characterized by the pursuit of understanding the innovation and its operation. During the persuasion stage, the organization develops a favorable or unfavorable attitude toward innovation, based mostly on perceived attributes such as relative advantage, compatibility, complexity, trialability, and observability. During the decision stage, the organization conducts activities that lead to the decision to embrace or reject an innovation. At this point, the company may benefit from utilizing a readiness assessment model to aid decision-making.

During the implementation stage, the decision-making unit put the new idea into practice. While the initial stages of adoption involve creative activities such as thinking about new ideas and making creative decisions, implementation is the process of incorporating this choice into a bureaucratic routine (Tornatzky; Fleischer, 1990). Finally, in the confirmation stage, the decision-making unit determines whether to continue with the innovation, i.e., the organization can reverse or preserve a previous decision. Maturity can only be achieved after a significant period of consistent operation in the environment (Botha, 2018). As a result, the assessment of organizational maturity starts at the confirmation stage, when innovation has already entered the company's *modus operandi* and it has been decided to continue using it.

Figure 6.1 illustrates the innovation-decision process as outlined in the Diffusion of Innovations (DOI) theory. This figure highlights the specific stage within the innovation implementation process where the application of readiness and Maturity Models becomes crucial.

Figure 6.1 - Innovation-decision process and RMs and MMs



Source: Adapted from Rogers (2003) – Diffusion of Innovations (DOI) theory

A Readiness Model will be important during the decision stage, when the decision-making unit must decide whether to accept or reject the innovation. A Readiness Model should address issues throughout the implementation phase. The implementation process may present challenges, as it transitions from a mental exercise of consideration and decision-making to the actual application of the idea. The readiness assessment encompasses the full implementation process, which doesn't end when the innovation is acquired but continues until it is put into operation. Therefore, the readiness assessment must still consider the challenges that arise regarding the precise utilization of the innovation during the implementation phase.

According to De Carolis *et al.* (2017), Readiness Models and Maturity Models are relative and related. Figure 6.1 illustrates a continuity between the evaluation of readiness and maturity. A decoupling point is also depicted in Figure 6.1, enabling the separation of instances during the life cycle of an innovation, during which the readiness and Maturity Models should be employed. This figure enables researchers to categorize their research as readiness- or Maturity Model-based, depending on the company's current situation regarding innovation.

Weiner (2009) argues that "Readiness for change" is a prerequisite for successfully implementing complex changes, underscoring the fact that readiness is an essential competence before implementing the change. As Maturity Models examine the development of an ongoing implementation, we can conclude that they are required from this point forward in the innovation life cycle.

Readiness and Maturity Models also differ based on their intended application. According to Snyder (2001), the failure rate for new implementations in this sector in the United States is primarily due to a failure to identify organizational risks associated with innovation. This risk assessment must be completed before deciding to accept an innovation; otherwise, the risk of unsuccessful implementation is very high. Still, according to Snyder (2001), a significant approach to assessing the potential hazards of an innovation is to examine the organization's readiness for it. As a result, Readiness Models help organizations avoid "false starts," which have been blamed for the notoriously large proportion of innovation failures (Lokuge *et al.*, 2019). Maturity Models attempt to characterize, measure, and improve a domain (Mettler; Ballester, 2021). Maturity Models are used for continuous improvement (Ahern; Aaron; Richard, 2008; Mettler, 2009; Paulk *et al.*, 1993) as well as self/third-party assessment (Fraser; Moultrie; Gregory, 2002; Mettler, 2009).

Effective integration of digital technologies and processes, adequate readiness, and preparation are indispensable (Khin; Kee, 2022). Because organizations have not yet developed a mature process for these technologies, we acknowledge that this study will use the term readiness model rather than maturity model to assess digital transformation. More precisely, the goal of this research is to provide a general framework to guide the creation of an organizational readiness model for the adoption of innovations using digital technologies in Operations and Supply Chain Management. Furthermore, we emphasize that research into readiness remains limited and this field of research remains deficient in comprehensive frameworks and empirical evidence. Therefore, we seek to shed light on issues related to assessing readiness rather than maturity when analyzing digital transformation within Industry 5.0 landscape.

6.2.2 Crafting an Effective Readiness Assessment Framework for Digital Innovation Adoption in the Industry 4.0 domain

Existing readiness models for Industry 4.0 and Operations and Supply Chain Management exhibit significant heterogeneity in their structure, dimensions, and development processes, with no consolidated guidelines to ensure comparability and reproducibility. Systematic reviews show that models differ widely in steps, criteria, and methodological rigor, resulting in fragmented practices and limited scientific robustness (Hizam-hanafiah; Soomro; Abdullah, 2024; Unlu; Demirors, 2023). Compounding this, most readiness models fail to adopt rigorous methodological principles, frequent shortcomings include the absence of iterative refinement, limited empirical validation, and poor documentation of design decisions (Becker; Knackstedt; Pöppelbuß, 2009; Mettler; Ballester, 2021). These weaknesses hamper benchmarking and replication, creating uncertainty for both researchers and practitioners seeking reliable approaches for readiness assessment.

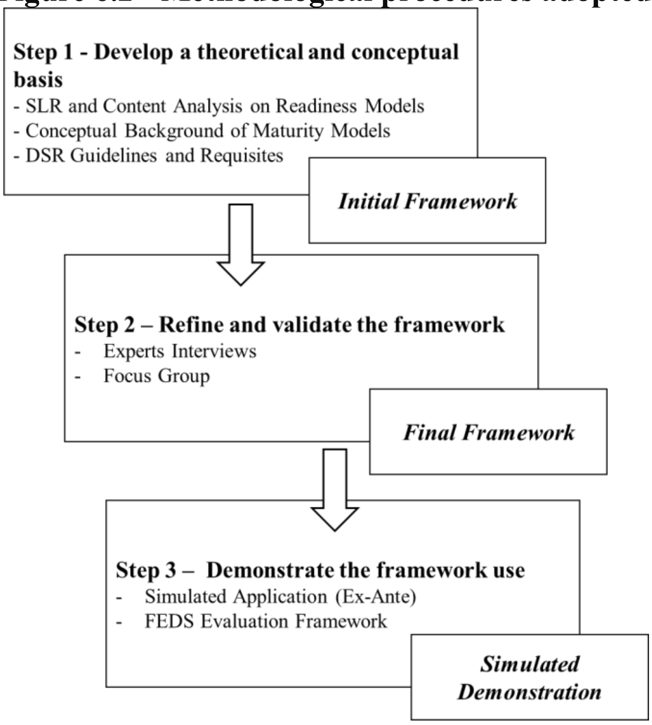
Design Science Research (DSR) offers a paradigm that directly addresses these gaps by emphasizing the creation of artifacts that solve real-world problems while adhering to scientific rigor (Hevner *et al.*, 2004). DSR principles (iterative design, multi-method evaluation, and comprehensive documentation) provide a robust foundation for developing readiness models that are both theoretically grounded and practically applicable, contributing to bridging the rigor–relevance gap in readiness model research (Gregor; Hevner, 2013).

In this study, DOI clarifies the stages of technology adoption and highlights why readiness models are critical at the Decision stage, reducing the risk of implementation failure. Complementarily, DSR provides the methodological paradigm to address this problem by guiding the development of artifacts that combine scientific rigor and practical applicability. Thus, while DOI explains the *"why"*, the need for readiness models in the innovation adoption process, DSR provides the *"how"*, the principles and process for designing a robust framework to support their development (Becker; Knackstedt; Pöppelbuß, 2009; Hevner *et al.*, 2004; Rogers, 2003).

6.3 Research Method

Our research adopts a multi-method approach structured in three stages and guided by the principles of Design Science Research (DSR): (i) a Systematic Literature Review (SLR) and Content Analysis to develop the conceptual foundation and an initial framework; (ii) expert interviews and focus groups to refine and validate the framework; and (iii) an ex-ante demonstration to verify its applicability before real-world use. Figure 6.2 summarizes this process.

Figure 6.2 - Methodological procedures adopted



Source: Author's own work.

6.3.1 Develop a theoretical and conceptual basis (Initial Framework)

An SLR was conducted following the three-stage approach of Tranfield, Denyer and Smart (2003) and Kitchenham and Charters (2007), planning, conducting, and reporting, in accordance with PRISMA recommendations (Moher *et al.*, 2015). Searches were performed in Scopus, Web of Science, and Engineering Village using two complementary search strings. The first focused on readiness in the context of Industry 4.0 and Industry 5.0, combining the terms "Industry 4.0", "I4.0", "Industry 5.0", and "I5.0" with "Readiness". The second addressed readiness for digital innovation more broadly, combining the terms “Digital innovation”, “Digitization”, and “Digitalization” with “Readiness”.

The inclusion criteria comprised: (1) articles that developed a model/instrument for assessing readiness to adopt innovations with digital technologies in the field of Operations and Supply Chain Management, (2) articles published in journals, (3) articles written in English, and (4) articles to which full access was possible.

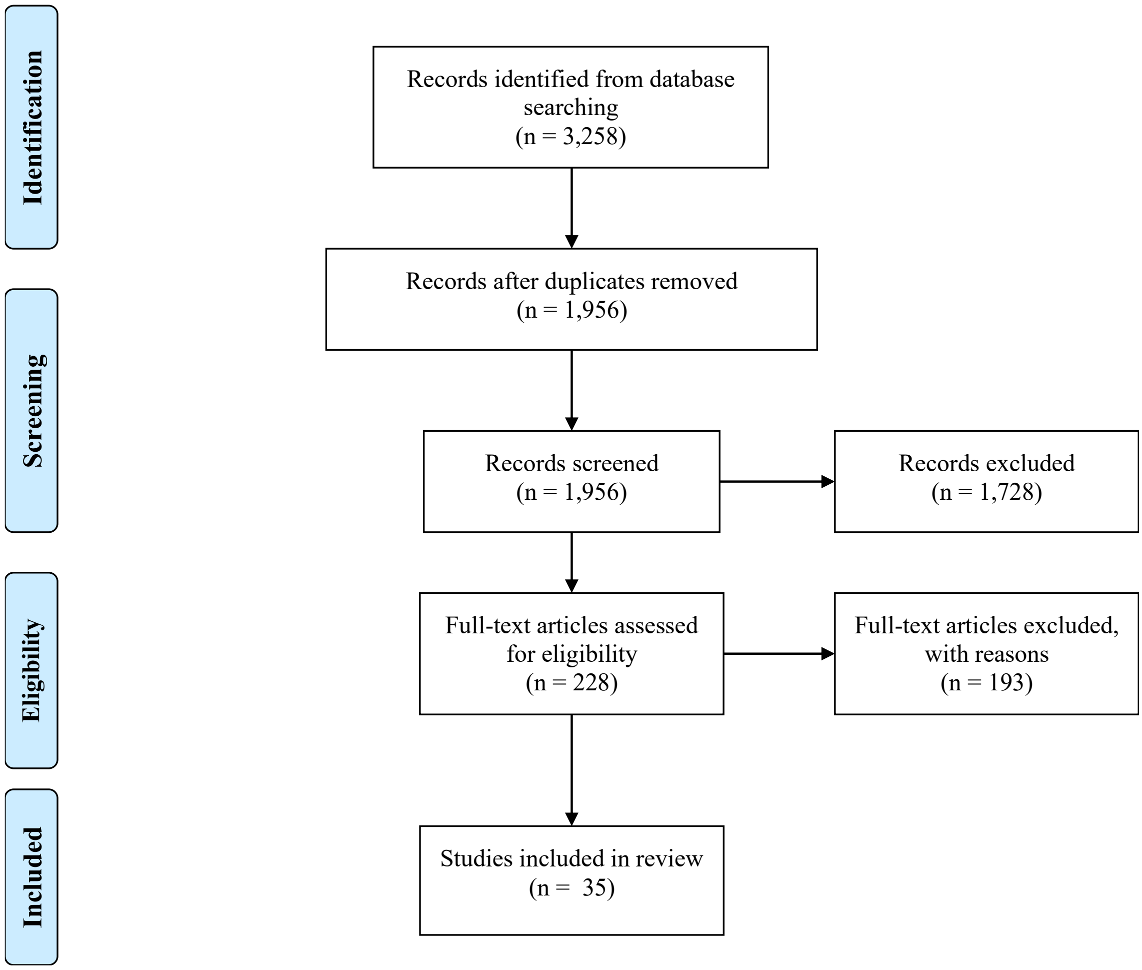
Regarding the exclusion criteria:

Models that provided insufficient information about the development approach, structure, and evaluation methodology were eliminated from the analysis, which is always useful information for recreating the findings. Because, according to Becker, Knackstedt and Pöppelbuß (2009), models can only be effectively compared when detailed documentation is supplied. Additional circumstances excluded from our analysis:

a) Models/instruments that assess the readiness of countries and service institutions (e.g., Almalki; Durugbo, 2024; Nhamo; Nhemachena; Nhamo, 2020; Sadeghi-Niaraki, 2020; Tripathi; Gupta, 2021) only in the Operations and Supply Chain Management context;
b) No papers were examined that used a model generated by a third party (e.g., Alcácer *et al.*, 2021; Barbosa *et al.*, 2025; Denicolai; Zucchella; Magnani, 2021). Only models/instruments whose step-by-step development was created and presented by the study;
c) Given the distinctions between maturity and readiness addressed in this study, no maturity models were examined (e.g., Mittal *et al.*, 2018; Wagire *et al.*, 2021).

The search returned 3,258 articles; 1,302 duplicates were removed, leaving 1,956 for screening. After title, abstract, and keyword screening, 1,728 were excluded. The remaining 228 articles were fully assessed against the inclusion and exclusion criteria, resulting in 35 papers selected for analysis (see Figure 6.3 — PRISMA flow diagram).

Figure 6.3 - PRISMA flow diagram



Source: Author's own work.

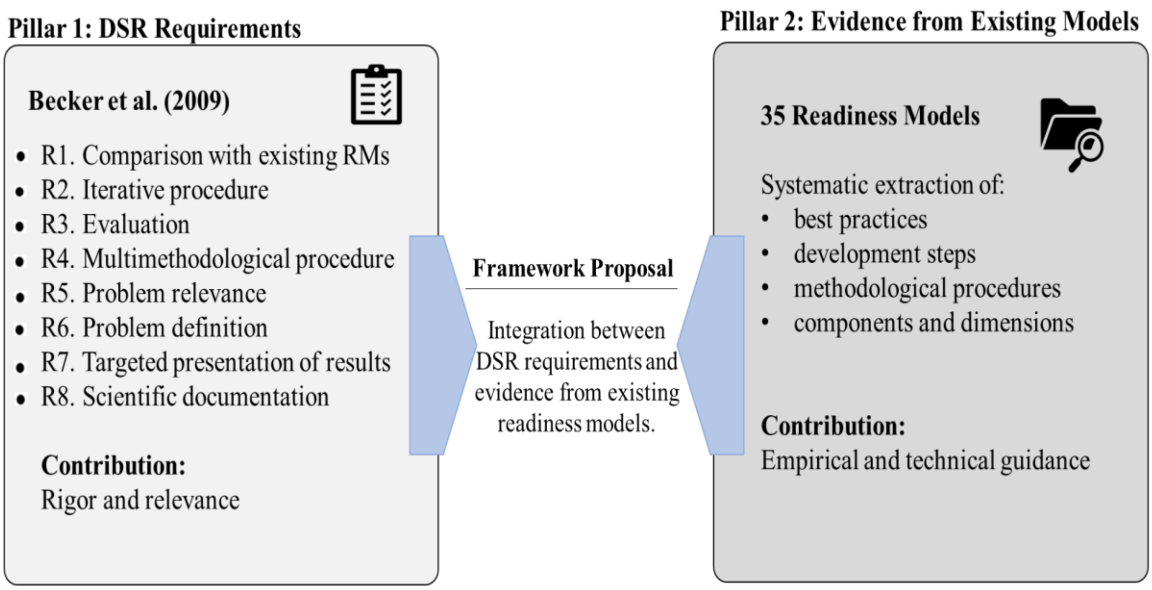
From the 35 selected papers, data was extracted and analyzed using two complementary frameworks. The first, proposed by Caiado *et al.* (2021) and outlined in Table 6.2, examined the fundamental components of each readiness model's structure, including the model's name, scope, dimensions and subdimensions, readiness levels, methods employed at each stage, and whether the model underwent empirical testing. The second framework applied the eight DSR requisites for model development proposed by Becker, Knackstedt and Pöppelbuß (2009): comparison with existing models (R1), iterative procedure (R2), evaluation (R3), multi-methodological procedure (R4), identification of problem relevance (R5), problem definition (R6), targeted presentation of results (R7), and scientific documentation (R8).

Content analysis was conducted across the 35 readiness models following Krippendorff (2019). This analysis not only compared structural aspects found across the examined models but also identified the most effective approaches that promote robust readiness models development. Results are organized in Table 6.2 and discussed in Sections 6.4.1.1 and 6.4.1.2.

6.3.2 Framework proposal

Our objective is to establish a framework that guides the development of a readiness model intended to incorporate innovations with digital technology in the field of Operations and Supply Chain Management. This framework should offer a systematic series of procedures and techniques to assist in the development of a readiness model that combines both theoretical and empirical validity. Because DSR is an approach that can combine theoretical development and empirical application (Holmström; Ketokivi; Hameri, 2009), the developed framework provides guidance based on eight requirements for developing readiness models/maturity models using DSR principles brought by Becker, Knackstedt and Pöppelbuß (2009). Furthermore, our framework also incorporates the primary methodologies and procedures identified in the 35 models examined in our SLR (see Figure 6.4).

Figure 6.4 - Basis for framework proposal: DSR Requirements and RMs



Source: Author's own work.

Based on the aspects shown in figure 6.4, we developed a first framework with a sequence of actions demonstrating what to do and how to proceed, what are the main elements that need to be designed, and what are the recommendations of methodological methods that may be applied in each of these steps. This framework was presented to experts aiming for its refinement and validation, more details can be found in section 6.3.3.

6.3.3 Refine and validate the framework (Final Framework)

This section presents the refinement and validation of the proposed framework, describing the expert-based refinement process and the subsequent validation through focus groups to assess its clarity, coherence, and applicability.

6.3.3.1 Framework refinement

In line with the Design Science Research (DSR) paradigm, the initial framework was submitted to expert-based refinement as an intermediate evaluation of the artifact. This stage aimed to assess the clarity, completeness, logical coherence, terminology, sequence of steps, and usefulness of the framework for guiding the development of readiness models in digital Operations and Supply Chain Management contexts. Expert-based refinement was considered appropriate because the proposed framework is both methodological and domain-oriented: it provides guidance for developing readiness models while being specifically aimed at digital innovation adoption in Operations and Supply Chain Management.

Experts were selected through purposive sampling based on their publications and experience with readiness models (RMs), maturity models (MMs), Industry 4.0/5.0, digital technologies, and/or Operations and Supply Chain Management. All experts had prior experience with readiness models and/or Maturity Models, providing a common methodological basis for evaluating the framework's structure, internal coherence, construction logic, and suitability as guidance for readiness model development. In addition, their varying experience in Operations and Supply Chain Management, Industry 4.0/5.0, digital technologies, and digital transformation supported the assessment of the framework's contextual relevance, terminology, and applicability to digital Operations and Supply Chain Management contexts. Thus, the panel combined a shared methodological background in readiness model/maturity model with complementary domain expertise.

The number of experts was not predetermined. Instead, data collection followed an iterative logic in which interviews were conducted until theoretical saturation was reached (Saunders *et al.*, 2018). Ten experts participated in the refinement process. Table 6.1 presents the expert panel profile, including educational qualification, position, experience with readiness/maturity models, and Operations and Supply Chain Management experience.

Table 6.1 – Experts profile

Expert code	Educational qualification	Position	Experience with RM/MM (years)	OSCM experience (years)
E1	PhD	Researcher/Professor	>10	>15
E2	PhD	Researcher/Professor	>5	>10
E3	PhD	Researcher/Professor	>10	>20
E4	PhD	Researcher/Professor	>5	>15
E5	PhD	Researcher/Professor	>10	>20
E6	PhD	Researcher/Professor	>5	>15
E7	PhD	Researcher/Professor	>5	>10
E8	PhD	Researcher/Professor	>5	>25
E9	PhD	Researcher/Professor	>10	>25
E10	PhD	Researcher/Professor	>10	>15

Author's own work.

Individual semi-structured interviews were conducted with each expert and lasted approximately one hour. The interviews focused on the framework's phases, elements, supporting strategies, sequence, terminology, methodological guidance, and practical usefulness. Experts were asked to assess whether the framework was clear, complete, logically structured, and sufficiently operational to support the development of readiness models. All suggestions were recorded, coded, and compared across interviews.

To assess theoretical saturation, the type, recurrence, and novelty of expert contributions were monitored throughout the interview process. In the early interviews, experts introduced new recommendations mainly related to the integration of substeps, merging of overlapping steps, adjustment of sequential logic, improvement of the framework layout, and incorporation of readiness-related terms across the stages. They also emphasized that the framework should clearly indicate both "what to do" and "how to do it" at each stage, reinforcing the need for a more operational and user-oriented structure.

As the interviews progressed, the feedback became increasingly recurrent. From the eighth interview onward, expert contributions were predominantly confirmatory, focusing on minor wording adjustments and reinforcing aspects already identified in previous interviews rather than introducing new elements. The ninth and tenth interviews confirmed this pattern, with no new constructs, steps, methodological recommendations, or substantial refinements emerging. Therefore, theoretical saturation was considered achieved following (Saunders *et al.*, 2018), as both code saturation, indicated by the absence of new constructs, and meaning saturation, indicated by the stabilization of interpretations, were reached.

The refinements suggested by the experts were incorporated into the framework before the subsequent validation stage. The detailed refinements and the resulting final version of the framework are presented in the results section.

6.3.3.2 Framework Validation

Following Tremblay, Hevner and Berndt (2010), focus groups were used as a qualitative procedure for artifact refinement and evaluation. Two rounds of focus groups were conducted to collectively assess the refined framework regarding its clarity, coherence, usability, applicability, and usefulness for supporting the development of readiness models in digital Operations and Supply Chain Management contexts. Each round involved three participants selected from the experts listed in Table 6.1 due to their extensive experience in the development and application of readiness and/or maturity models in the Operations and Supply Chain Management field. The use of the same experts across both rounds was intentional, as the objective was to evaluate the revised artifact collectively and verify whether the recommendations from the individual refinement stage had been adequately incorporated. Each focus group lasted approximately two hours and followed a structured discussion guide. In the first round, the framework refined from the expert interviews was presented to the participants, including its objective, structure, components, recommended steps, supporting methods, and potential applications. Experts discussed the framework's comprehensibility, usability, relevance of steps and components, appropriateness of the suggested scientific methods, coherence of the recommended sequence, and usefulness for developing readiness models.

The interactions, responses, remarks, and insights generated during the discussion were documented. Based on these records, the main proposals and points of convergence were summarized after the first round, allowing suggested adjustments to be incorporated into the framework. After these modifications, the revised framework was presented to the same experts in a second focus group round. This second round had a more confirmatory purpose, as participants assessed whether the adjustments had improved the framework and whether any remaining issues, ambiguities, or inconsistencies still needed to be addressed. To reduce potential confirmation bias, both focus group rounds followed a structured discussion guide and explicitly encouraged participants to identify remaining problems, inconsistencies, or unclear elements. The feedback obtained in the second round led mainly to additional improvements in the clarity of the framework procedures. The detailed framework components and sequence are presented in Section 6.4.2.

6.3.4 Demonstrate the framework use (Simulated demonstration)

To complement expert validation and ensure logical consistency before real-world application, an ex-ante evaluation was conducted through a conceptual simulation. This demonstration aimed to assess the framework's applicability, completeness, and coherence by simulating its use in a plausible scenario of blockchain adoption in Supply Chain Management (the TradeLens case). Following the guidelines of the Framework for Evaluation in Design Science Research (FEDS) (Venable; Pries-Heje; Baskerville, 2016), the evaluation episode was designed as an artificial, ex-ante assessment, focusing on three properties: utility, completeness, and logical coherence. The simulation illustrated how the framework would guide the development of a readiness model, including the definition of dimensions, readiness levels, and an assessment instrument aligned with the technological domain. This approach provided evidence of the framework's potential effectiveness and applicability before any empirical instantiation.

6.3.5 Triangulation in Framework Development and Validation

To ensure scientific rigor and practical relevance, methodological triangulation was adopted across all phases, integrating multiple sources and methods to mitigate the limitations of relying on a single approach (Creswell; Creswell, 2018; Hevner *et al.*, 2004b). In the context of DSR, this principle aligns with the guidelines for combining theoretical and empirical insights to produce robust artifacts.

During the framework construction phase, three complementary strategies were combined: (i) an SLR to establish a solid conceptual foundation and identify common components and methodological practices in existing readiness models; (ii) the incorporation of DSR principles and Maturity Model guidelines to reinforce the theoretical basis and ensure compliance with established design requirements; and (iii) iterative refinement through expert interviews, ensuring alignment with real-world practices and contextual relevance.

During the validation phase, triangulation continued through: (i) individual expert evaluations via ten in-depth interviews, assessing clarity, relevance, and logical coherence; (ii) two rounds of focus groups, enabling qualitative validation of the framework's usability and applicability; and (iii) an ex-ante conceptual demonstration following FEDS guidelines (Venable; Pries-Heje; Baskerville, 2016), simulating the framework's application in the TradeLens case to assess utility, completeness, and logical consistency prior to empirical instantiation.

6.4 Results and Discussion

This section presents the results and discussion of the study, describing the development of the proposed framework for designing readiness models in digital Operations and Supply Chain Management contexts. It first discusses the findings from the systematic literature review and content analysis, highlighting key components, structures, and methodological practices identified in existing readiness models. Subsequently, it presents the initial framework and its refinement and validation process, culminating in the final framework and its main components and structure.

6.4.1 Theoretical and conceptual basis (Initial Framework)

The 35 readiness models examined correspond to articles that developed a tool for evaluating organizational readiness to adopt digital technology innovations. Analysis of these models revealed a lack of uniformity in readiness model construction, confirming the need for a generic framework grounded in well-established methodological criteria. Although readiness models and Maturity Models differ in scope, they share a similar structure in terms of constituent elements (such as dimensions, items, and readiness levels) which justifies the use of Maturity Model-derived criteria (Becker; Knackstedt; Pöppelbuß, 2009; Caiado *et al.*, 2021; Hevner *et al.*, 2004) to analyze and benchmark the reviewed models.

6.4.1.1 Components and Procedures of readiness models in literature

Table 6.2 presents the structural comparison of the 35 analyzed readiness models based on the criteria of Caiado *et al.* (2021).

Table 6.2 - Model structure of analyzed RMs

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Lokuge *et al.* (2019) Information & Management	Organizational readiness for digital Innovation construct	Digital innovation in organizations	Dimensions 1. Resource Readiness 2. IT Readiness 3. Cognitive Readiness 4. Partnership Readiness 5. Innovation Valance 6. Cultural Readiness 7. Strategic Readiness (7 dimensions)	Three measures for each dimension (21 items)	-	Literature Review + Experts's interview + Survey	Yes. The survey instrument was applied to representatives of 350 organizations
Pacchini *et al.* (2019). Journal - Computers in Industry	Industry 4.0 Implementation Readiness Model	Industry 4.0/Manufacturing	Factors/enabling technologies 1. Big data 2. Internet of Things 3. Cloud Computing 4. Augmented Reality 5. Cyber-Physical Systems 6.Autonomous Robots 7. Additive Manufacturing 8. Artificial Intelligence (8 dimensions)	Six prerequisites for each enabling technology (48 items)	1. Embryonic Initial 2. Initial 3. Primary 4. Intermediate 5.Advanced 6. Ready (6 levels)	Literature review+ experts' interview + Case Study	Yes. Brazilian auto-parts manufacturing industry
Vrchota and Pech (2019). Journal - Applied Sciences	Index of Industry 4.0 (VPi4)	Manufacturing industry	Dimensions 1. Data and availability of human capital 2. Core infrastructure of Industry 4.0 3. Higher level of Industry 4.0 (3 dimensions)	13 items	Index of Industry 4.0 (VPi4) 0-100%	Expert interviews + Survey	Yes (survey applied to 276 enterprises).
Chonsawat and Sopadang (2020). Journal - Applied Sciences	SMEs' 4.0 Readiness Indicators	SMEs	Dimensions 1. Organizational Resilience, 2. Infrastructure System, 3. Manufacturing System, 4. Data Transformation, 5. Digital Technology. (5 dimensions)	23 items	Levels: • Not achieved • Partially achieved • Achieved • Fully achieved (4 levels)	Literature Review + Case study	Yes. A small enterprise size in Thailand, which is conducted in the plastics industry.
Pirola *et al.* (2020). Journal of Manufacturing Technology Management	Digital readiness assessment of Italian SMEs	SMEs	Dimensions • Strategy • People • Processes • Technology • Integration (5 dimensions)	24 items	DRL 1 = $1<I\leqslant1.8$ DRL 2 = $1.8<I\leqslant2.6$ DRL 3 = $2.6<I\leqslant3.4$ DRL 4 = $3.4<I\leqslant4.2$ DRL 5 = $4.2<I\leqslant5$ (5 levels)	Literature Review + Pilot case study + Multiple case studies	Yes. 20 manufacturing SMEs

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Balasubramani an *et al.* (2021). Journal - Technological Forecasting & Social Change	Multi-dimensional blockchain readiness assessment framework for the healthcare sector	Healthcare/ SC	Dimensions 1. Key stakeholders 2. Key readiness dimensions (individual readiness) 3. Key facilitating conditions 4. Collaboration between stakeholders (4 dimensions)	12 items	Readiness levels: • Low • Moderate • Moderate to High • High (4 levels)	Systematic Literature Review + Case Country	Yes. UAE Healthcare Sector (case country)
Bastos *et al.* (2021). Journal - IEEE Access	RAMI 4.0 Ontology Standard Readiness Assessment	Manufacturing Industry	Dimensions 1. Hierarchy axis 2. Life-cycle and Value stream axis 3. Layer axis (3 dimensions)	17 items	Readiness degree • Embryonic • Underdeveloped • Intermediate • High intermediate • Completely ready (5 levels)	Case study	Yes. Automotive industrial complex located in Brazil
Irannezhad e al. (2021). Journal - Applied Soft Computing	Blockchain readiness assessment and management	SC	Dimensions F1 Strategic requirements F2: Business model, structure and process capability F3: Technical requirements F4: Data preparation F5: Contextual requirements F6: Management system F7: Change management F8: Knowledge and skills (8 dimensions)	38 items	Readiness levels: • No readiness (NR) • Very weak readiness (VWR) • Weak readiness (WR) • Moderate readiness (MR) • Strong readiness (SR) • Very strong readiness (VSR) (6 levels)	Literature review + Experts (MCDM techniques) + Case study	Model Validation: A pharmaceutical SC
Khan *et al.* (2021). Journal - Knowledge-Based Systems	Digital supply chain (DSC) readiness	Digital Supply Chain/ Manufacturing	-	1. Information and communication technology (ICT) policies 2. Worker IT skills 3. Supplier–buyer relationship 4. Relationship with customer 5. Use of smart technologies in WH 6. Use of smart technologies in logistics 7. Use of smart technologies in production 8. IT network infrastructure 9. Training policy (9 items)	0-1	Literature Review + Experts (MCDM techniques) + Case Study	Validation: Indian manufacturing company

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Saad *et al.* (2021). Journal of Manufacturing Technology Management	Smart SME technology readiness assessment methodology in the context of industry 4.0	Industry 4.0/Manufacturing/ SMEs	Criteria • Design Execution • Design System Flexibility • Design Real-Time Data Management (3 dimensions)	Drivers Design Execution • Decision Making • Simulation modeling • Digital prototyping Design System Flexibility • Collaborative Customization • Agility • Collaborative Design Design Real-Time Data Management • Data Acquisition • Data Analytics • Data Security (9 items)	Si=0 Outsider Si=1 Beginner Si=2 Learner Si=3 Experienced Si=4 Leader (5 levels)	Literature Review + Experts (MCDM techniques) + Case Study	SME Manufacturer in the sanitary ware industry
Sözbilir, (2021). Journal - Technological and Economic Development of Economy	Industry 4.0 adaptation potential scale (4IRAPS)	I4.0 in organizations	Factors 1. Interested in industry 4.0 2. Effort for adaptation to industry 4.0 3. Readiness for industry 4.0 4. Pessimism about industry 4.0 (4 dimensions)	Items 17 items	-	Literature review + Experts panel + Survey	No.
Zoubek and Simon (2021). Journal - Applied Sciences	Readiness of Internal Logistics for Industry 4.0	Manufacturing industry	Dimensions/Internal logistics activities • Manipulation • Storage • Supply • Packaging • Material identification (5 dimensions)	14 items	Level 0 = 0% Level 1 = 0% Level 2 = 0% - 25% Level 3 = 25% - 50% Level 4 = 50% - 75% Level 5 = 75% - 100% (6 levels)	Literature Review + Experts panel + Pilot case study + Multiple case study	Yes. 29 industrial enterprises in Czech Republic
Demir *et al.* (2022). Engineering Management Journal	Smart and Sustainable SC Readiness and Maturity model (S3RM)	SC	Dimensions • Smartness • Availability • Integrity • Adaptability • Sustainability • Social • Environmental • Economic (8 dimensions)	44 items	Score 0 – 5 (6 levels)	Literature Review + Experts panel + Case study	Yes. Automotive sector company

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Felippes *et al.* (2022). Journal - Production & Manufacturing Research	3D-CUBE readiness model for industry 4.0	Manufacturing industry	Dimensions • Organizational enablers • Technological enablers • Processess Maturity (3 dimensions)	Subdimensions Organizational enablers • Organizational Strategy • Human Workforce Technological enablers • Production Technology • Information Technology Processes Maturity • Product-Service Development • Order Fulfilment (6 items)	Levels Level 0 – Not initiated Level 1 - Initiated Level 2 - Managed Level 3 – Defined Level 4 - Optimized Level 5 – Self-Adapted	Literature Review + Case study + Experts panel	Yes. Questionnaire practical application - manufacturing company that produces metal-based components for civil construction
Khin and Kee, (2022). International Journal of Computer Integrated Manufacturing	SMEs' readiness for I4.0	Manufacturing industry	Dimensions • Managerial Readiness • Operational Readiness • Technological Readiness • Financial Capability • Technological Capability • Perceived Benefits • Perceived Opportunities • Competitive pressure • Customers Need • Financial Support (10 dimensions)	-	Low Medium High	Literature Review + Survey	Yes (survey applied to 110 PMEs manufacturing companies)
Lassnig *et al.* (2022). Journal of Manufacturing Technology Management	Digital Readiness Check (DRC)	SC	Dimensions 1. Strategy 2. Employees 3. Initiation of business transactions 4. Digitalization of the SC based	12 items	-	Literature review + Survey	Yes (survey applied to 409 companies)

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Ramanathan and Samaranayake (2022). Journal of Manufacturing Technology Management	Industry 4.0 Readiness Assessment Framework (I4.0RAF)	Manufacturing industry	Dimensions/Determinants • Strategy and Organization • Plant and equipment • IT systems and data management • Human resources • Product definition • Managing operations: energy consumption management • Managing operations: quality management • Managing operations: SCM (8 dimensions)	33 items	Status of Industry 4.0 readiness • 0–33 Hesitators • 34–66 Potentialists • 67–99 Experienced • 100–132 Experts or Frontrunners	Literature Review + Case study	Yes. Case study in a glass manufacturing consumer product company
Trstenjak *et al.* (2022). Journal - Sensors	Industry 4.0 Readiness Calculation	Manufacturing industry	Dimensions/Elements of industry 4.0 • Smart Process Planning • Infrastructure • Organization and Human Resources (3 dimensions)	35 items	F= 0 - 0,25 Industry 1.0 F= 0,25 - 0,5 Industry 2.0 F= 0,5 – 0,75 Industry 3.0 F= 0,75 – 0,99 Industry 3.5 F= 1 Industry 4.0	Literature Review + Experts (MCDM techniques) + Case study	Yes. Croatian metal machining company
(Wankhede and Vinodh, 2022). Journal - Benchmarking	Industry 4.0 (I4.0) readiness assessment model	Manufacturing industry	Criteria: 1. Technology 2. Organization and Management 3. Process 4. Legislation 5. Product 6. Employee (6 dimensions)	50 items	Levels: • Extremely I4.0 [EI] • Very I4.0 [VI] • Good I4.0 [GI] • Fairly I4.0 [FI] • Slowly I4.0[SI]	Literature review + Experts (MCDM techniques) + Case study	Yes. Automotive component manufacturing organization.
Ansari *et al.* (2023). International Journal of Quality & Reliability Management	Industry 4.0 readiness model for new technology exploitation	Manufacturing industry	Dimensions • Strategy and organization • Smart Factory • Smart operations • Smart products • Data-driven services • Employees • Marketing and customer access • Legal consideration • Culture • Leadership (10 dimensions)	37 items	Readiness levels • Level 0 Stranger • Level 1 Novice • Level 2 Intermediate • Level 3 Learned • Level 4 Specialist	Literature Review + Experts panel	No.

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Monshizadeh *et al.* (2023). International Journal of Production Economics	Industry 4.0 readiness model	Manufacturing industry	Dimensions • Operational Readiness • Organizational Readiness • Technological Readiness (3 dimensions)	16 items	Readiness Level • very low: 0–0.2 • low: 0.2–0.5 • medium: 0.5–0.65 • high: 0.65–0.8 • very high: 0.8–1	Literature Review + Survey	Yes. Survey with 257 experts from the automotive industry
Gençer *et al.* (2025). Technology Analysis & Strategic Management	Digital Transformation Index	Business Organizations	Dimensions • Customer relations & marketing • Cybersecurity • Data management tools • External environment • Human resources • Investment & finance operations • Logistics & supply chain operations • Organisational • Partnership • Product development process • Production operations • Strategy • Technological resources • Top management (14 dimensões)	80 items	-	Systematic Literature Review + Comparison with widely used models	Yes. Pilot study with 29 companies for index refinement and external validation.
Govindan and Arampatzis (2023). Electronic Commerce Research and Applications	Industry 4.0 Readiness Framework	Manufacturing industry	Dimensions • Business Models & Products • Market & Sales • Value Chains & Operations • IT Infrastructure • Legal & Security • Organization & Strategy (6 dimensions)	36 items	Score (1-4) (4 levels)	Literature review + Expert validation + Case study	Yes. Case study in Danish automotive supplier

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Jamouli *et al.* (2023). Data and Metadata	Fuzzy Readiness Model I4.0	Manufacturing industry	Dimensions • Organizational Maturity • Technology Maturity • Process Maturity (3 dimensions)	Indicators Organizational Maturity • Organizational strategy • Workforce (Human Factors) Technology Maturity • Production technology • Information technology Process Maturity • Product-service development • Order fulfillment (6 items)	0-1	Literature review + expert-driven modeling + case study	Yes. Two cases: a multinational automotive company and an SME in the clothing industry.
Zhao *et al.* (2023). Frontiers of Information Technology & Electronic Engineering	PIMRI – Process-Industry Intelligent Manufacturing Readiness Index	Process industry	Races • Process • Organization • Technology • Intelligence (4 dimensions)	249 items	Readiness Level L0 - Initial (0<L<0.8) L1 - Planning (0.8⩽L<1.8) L2 - Canonical (1.8⩽L<2.8) L3 - Integrated (2.8⩽L<3.8) L4 - Optmizing (3.8⩽L<4.8) L5 - Leading (4.8⩽L<5.0)	Literature review + expert validation + case-based organizational assessment	Yes. Applied to 196 companies.
Tavana *et al.* (2025). Journal of Industrial and Production Engineering	HSM Digitalization Readiness	Industrial SMEs	Criteria • Technology • People • Strategy • Leadership • Process • Innovation (6 dimensions)	25 items	Ranks alternatives • in-house • off-the-shelf • outsourcing	Literature review + expert validation + multi-criteria decision modeling + case study	Yes. Applied in a real industrial SME (home appliances, SE Asia)
De Larmelina *et al.* (2025) International Journal of Advanced Manufacturing Technology	Digital Twin Readiness Framework	Manufacturing/OSCM	Criteria • Simulation & Predictive Analytics • Real-Time Monitoring & Optimization • Integration & Collaboration (3 dimensions)	9 drivers (3 per dimension), each associated with 2 enabling technologies, totaling 18 items	Readiness levels Outsider (0.0 < R ≤ 0.5) Beginner (0.5 < R ≤ 1.5) Learner (1.5 < R ≤ 2.5) Experienced (2.5 < R ≤ 3.5) Leader (3.5 < R ≤ 4.0)	Literature review + expert-driven modeling + case study	Yes — validated through a case study in a Brazilian textile SME

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Kumar and Sharma (2025) Business Process Management Journal	Digital Readiness Assessment Maturity Model	SMEs	Solution dimensions • Developing a digital strategy and action plan for digitization • Development of IT infrastructure and automation • Strategic collaborations with internal and external partners • Launching skill/training programs • Coordination among key stakeholders • Management of internal processes considering digitization and integration • Application of product data and information management tools • Use of real-time product/process data • Implementing production/order planning and scheduling decision support • Implementing data analytics for online monitoring and maintenance • Adoption of traceability technologies to identify products and components • Leveraging traditional manufacturing systems with automated systems • Development of integration of information systems • Digitization of inbound/outbound logistics with operations (14 dimensions)	41 prerequisites	• I Embryonic ($0 \leq R0 < 10$) • II Initial (10–25) • III Primary (25–50) • IV Intermediate (50–75) • V Advanced (75–90) • VI Ready & Maintenance (90–100)	Systematic literature review + expert workshop + survey + case studies	Yes — applied in four sector-specific case studies
Pandey *et al.* (2025) Discover Sustainability	TOE-P Framework to asses I4.0 readiness	Sugar industry (SMEs, India)	Dimensions • Technology readiness • Organizational readiness • Environmental readiness • Process readiness (4 dimensions)	18 subdimensions (This count is derived from qualitative description; the article does not provide a consolidated list or official numbering.)	-	Systematic literature review + expert interviews + case studies	Yes. 4 Indian companies.

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Brückner *et al.* (2025) International Journal of Information Management Data Insights	Digital Index for assessing industry 5.0 readiness	SMEs in manufacturing and services	Dimensions • Digitalization strategy • IT infrastructure • Data management and security • Human-centered design • Sustainability (5 dimensions)	54 items	-	Systematic literature review (SLR) + Expert interviews + Survey + Prototype development + Pre-testing	Partial. Prototype without field results; pre-tests/pilots planned.
Cuevas-Lopez-de-Baro *et al.* (2025) Journal of Industrial Information Integration	Industry 5.0 assessment model	Cross-industry	Perspectives • Overarching • Sustainability • Human-centricity • Resilience (4 dimensions)	64 guiding questions	Readiness levels 0 – Not Initiated 1 – Exploration Phase 2 – Partial Implementation 3 – Advanced Implementation 4 – Fully Integrated 5 – Industry Benchmark	Systematic Literature Review + Expert validation	Validated by experts (not pilot-tested in companies)
Musyarofah *et al.* (2025) Journal of Open Innovation	IERI – Industrial Estate Readiness Index	Industrial estates	Factors • Investment • SC • IE management • Institutional • Academic • Regulation • Market (7 dimensions)	22 indicators	Very Low Low Moderate High Very High	Systematic literature review + expert interviews + multiple case studies	Yes. Multiple real-world case studies (30 industrial estates).
Fahim Faisal *et al.* (2024) Heliyon	Industry 4.0 Readiness Model	Manufacturing industry	Dimensions • Management & Leadership • Planning & Strategy • Smart Products & Machines • Business Process • Employee & Training • Customer's Feedback (6 dimensions)	17 items	0 – Outsiders 1 – Novice 2 – Survival 3 – Professional	Systematic literature review + expert interviews + case study	Yes. Validated through a single real-world case study (garment industry in Bangladesh).

Authors and source	Artifact/model name	Field application	Dimensions	Items	Readiness levels	Methodologies	Practically tested?
Ansari *et al.* (2025) Journal of Manufacturing Technology Management	Industry 4.0 Readiness Assessment Model	Manufacturing industry	Dimensions • Strategy & Organization • Smart Factory • Smart Operations • Smart Products • Data-driven Services • Employees • Marketing & Customer Access • Legal Considerations • Culture • Leadership & Management (10 dimensions)	10 dimensions, each with 4–7 indicators (total ≈ 45 items)	0 Stranger 1 Novice 2 Intermediate 3 Learned 4 Specialist	Systematic literature review + expert interviews + case study	Yes. Validated through a real-world case study in a large home appliance manufacturing company.
De Carolis *et al.* (2025) International Journal of Production Research	DREAMY – Digital REadiness Assessment MaturitY	Manufacturing industry	Dimensions • Management and Execution • Monitoring and Control • Technology • Organisation (4 dimensions)	174 questions distributed across the areas and dimensions.	Readiness Levels • Initial • Managed • Defined • Integrated & Interoperable • Digital-oriented	Literature review + Expert consultations + Multiple industrial cases	Yes. Validated through case studies and applied to 250+ manufacturing companies.

Source: Author’s own work.

The reviewed models cover a wide range of application fields, with most focused on manufacturing (Jamouli, 2023; Vrchota; Pech, 2019) and Supply Chain Management (Demir *et al.*, 2023; Irannezhad *et al.*, 2021), aligning with the Operations and Supply Chain Management scope of this study. Several models specifically target SMEs (Brückner *et al.*, 2025; Khin; Kee, 2022), digital Supply Chains (Khan *et al.*, 2021; Lassnig *et al.*, 2022), or blockchain adoption (Balasubramanian *et al.*, 2021; Irannezhad *et al.*, 2021).

Dimensions constitute a key component of readiness models or maturity models, representing categorical groups or areas defined using quantitative indicators, often sourced from data collected from a particular system (Alcácer *et al.*, 2021; Rajnai; Kocsis, 2018). Dimensions range from 3 to 14 across the reviewed models, with 3 being the most common. Each dimension is assessed through items (questions, subdimensions, or indicators) ranging from 6 to 174. These items serve as evaluation criteria, culminating in a final score or index (Rajnai; Kocsis, 2018). Readiness levels serve as the framework for the scale, organized in ascending order along a numerical continuum, ranging from the lowest to the highest level (Zoubek; Simon, 2021). Readiness levels typically range from 3 to 6, with 5 levels being the most prevalent, arranged along a numerical continuum from lowest to highest preparedness.

Methodologically, literature reviews and expert interviews are the most common approaches for defining dimensions and items (De Carolis *et al.*, 2025; Lokuge *et al.*, 2019; Pacchini *et al.*, 2019). MCDM techniques (such as Fuzzy Inference Systems, AHP, and DEMATEL) are frequently used for item weighting and prioritization (Irannezhad *et al.*, 2021; Khan *et al.*, 2021). Of the 35 models reviewed, 33 underwent practical testing, primarily through case studies or surveys.

6.4.1.2 Analyzing Existing Readiness Models considering Design Science Research Principles

The 35 models were assessed against the eight DSR requisites defined by Becker *et al.* (2009), based on the seven design science guidelines of Hevner *et al.* (2004). The findings for each requisite are summarized below.

Comparison with existing Readiness Model*s (R1)*

Before initiating the construction of a new model, it is imperative to recognize the need for such an endeavor. The necessity must be supported by a comparison of existing models (Becker; Knackstedt; Pöppelbuß, 2009). Twenty-nine of the 35 models conducted an initial comparison of existing readiness models, primarily through literature reviews identifying strengths and weaknesses of prior work (Felippes *et al.*, 2022; Monshizadeh *et al.*, 2023; Pirola; Cimini; Pinto, 2020; Trstenjak *et al.*, 2022; Wankhede; Vinodh, 2023). Ansari *et al.* (2023), for instance, systematically examined existing I4.0 readiness models to identify inconsistencies in dimensional coverage and level structuring, directly informing their proposed model. Comparative analysis not only justifies the development of new models but also guides their conceptual design.

Iterative Procedure (R2)

Models must be constructed through a search process, in which solutions are sought iteratively, proposed modified, evaluated, and refined/ improved when necessary (Becker; Knackstedt; Pöppelbuß, 2009). Twenty-nine of the 35 models described some form of iterative refinement. Lokuge *et al.* (2019), for example, used Q-Sort, a pre-test, a pilot study, and a quantitative survey in successive cycles, enabling the consolidation of measures and the inclusion of new constructs. The six models that reported no iterative procedure represent a methodological weakness, as iteration is central to producing reliable and well-grounded artifacts (Becker; Knackstedt; Pöppelbuß, 2009).

Evaluation (R3)

The evaluation requirement states that all model development principles and assumptions, including findings, must be iteratively assessed using suitable scientific methodologies (Becker; Knackstedt; Pöppelbuß, 2009; Hevner *et al.*, 2004). All 35 models evaluated intermediate or final results of the artifact design process. The most common evaluation methods were expert interviews and case studies. Pirola, Cimini and Pinto (2020) evaluated a model draft through two pilot cases before applying the validated version across 20 firms. Govindan and Arampatzis (2023) applied their framework in a real manufacturing company, performing barrier analysis via DEMATEL. These approaches demonstrate how evaluation methods can rigorously establish the goodness and efficacy of an artifact (Hevner *et al.*, 2004).

Multi-methodological Procedure (R4)

Because many techniques can be utilized to create an artifact and evaluate intermediate outputs, design science typically employs a multi-methodological approach (Hevner *et al.*, 2004). Most models adopted a multi-method approach, combining literature reviews, expert interviews, case studies, and/or surveys (Irannezhad *et al.*, 2021; Lokuge *et al.*, 2019; Pacchini *et al.*, 2019). Ansari and Barati (2025) illustrate this well, integrating an SLR, expert screening via Content Validity Ratio (CVR), and a Delphi method. The mix of methods must be well-founded and carefully calibrated to ensure rigor (Becker; Knackstedt; Pöppelbuß, 2009).

Identification of Problem Relevance (R5)

It is necessary to express the significance of the problem to be solved using an artifact developed for researchers and/or practitioners (Becker; Knackstedt; Pöppelbuß, 2009). Most models demonstrated problem relevance, even without explicitly referencing DSR requirements. Studies consistently justified the need for a new readiness model by highlighting gaps in existing tools, such as the fragmented nature of available assessments (De Carolis *et al.*, 2025) or the uneven application of I4.0 skills across operations (Demir *et al.*, 2023), reinforcing that any new artifact must address a real and unresolved need (Hevner *et al.*, 2004).

Problem Definition (R6)

The artifact's purpose is to address unresolved issues, defined by Hevner *et al.* (2004) as the gap between a system's current state and its ideal or goal state. Most models clearly defined the gap their artifact addressed. Pirola, Cimini and Pinto (2020) framed the problem as the absence of a tool supporting SMEs in assessing readiness for Smart Manufacturing. Irannezhad *et al.* (2021) targeted the lack of a model enabling Supply Chain decision-makers to identify, analyze, and prioritize blockchain adoption activities.

Clear problem definition is essential, as the solution must precisely represent the condition it aims to resolve.

Targeted Presentation of Results (R7)

Results must be presented to both technology- and management-oriented audiences (Becker; Knackstedt; Pöppelbuß, 2009; Hevner *et al.*, 2004). Several models fulfilled this effectively, offering self-assessment questionnaires, radar charts, and visual benchmarking tools (De Carolis *et al.*, 2025; Felippes *et al.*, 2022; Monshizadeh *et al.*, 2023; Ramanathan; Samaranayake, 2022). Accessible presentation enhances both practical adoption and the development of a replicable knowledge base for future research.

Scientific Documentation (R8)

Researchers, unlike practitioners such as technicians and managers, should not only offer outcomes but also prioritize documenting the study process (Becker; Knackstedt; Pöppelbuß, 2009; Hevner *et al.*, 2004). Most models documented the research process, though with varying levels of detail. Standout examples include Khan *et al.* (2021), who provided comprehensive documentation of design and evaluation methods, and Felippes *et al.* (2022), whose appendix included a full self-assessment questionnaire. Thorough documentation is critical for replicability and for establishing a foundation for future extensions (Hevner *et al.*, 2004).

6.4.1.3 Framework proposal (Initial Framework)

In our framework proposal, we adhere to the principles of Design Science Research (DSR), which is an appropriate methodological paradigm for developing new artifacts intended to solve organizational problems (Hevner *et al.*, 2004). Its cyclic process of building characterizes DSR, comprehending, and evaluating the results generated by an artifact, ensuring both its practical relevance and scientific rigor (Holmström; Ketokivi; Hameri, 2009). This is particularly pertinent to our study, which seeks to address the absence of a universally recognized framework for constructing readiness models in Industry 4.0.

The essence of DSR lies in its goal-oriented nature: producing artifacts that can meaningfully improve existing situations or solve problems (Simon, 1996). Our proposed framework mirrors this ethos, beginning with a clear definition of the problem organizations face with digital readiness and progressing through systematic steps to develop a model that is both robust and applicable in real-world contexts.

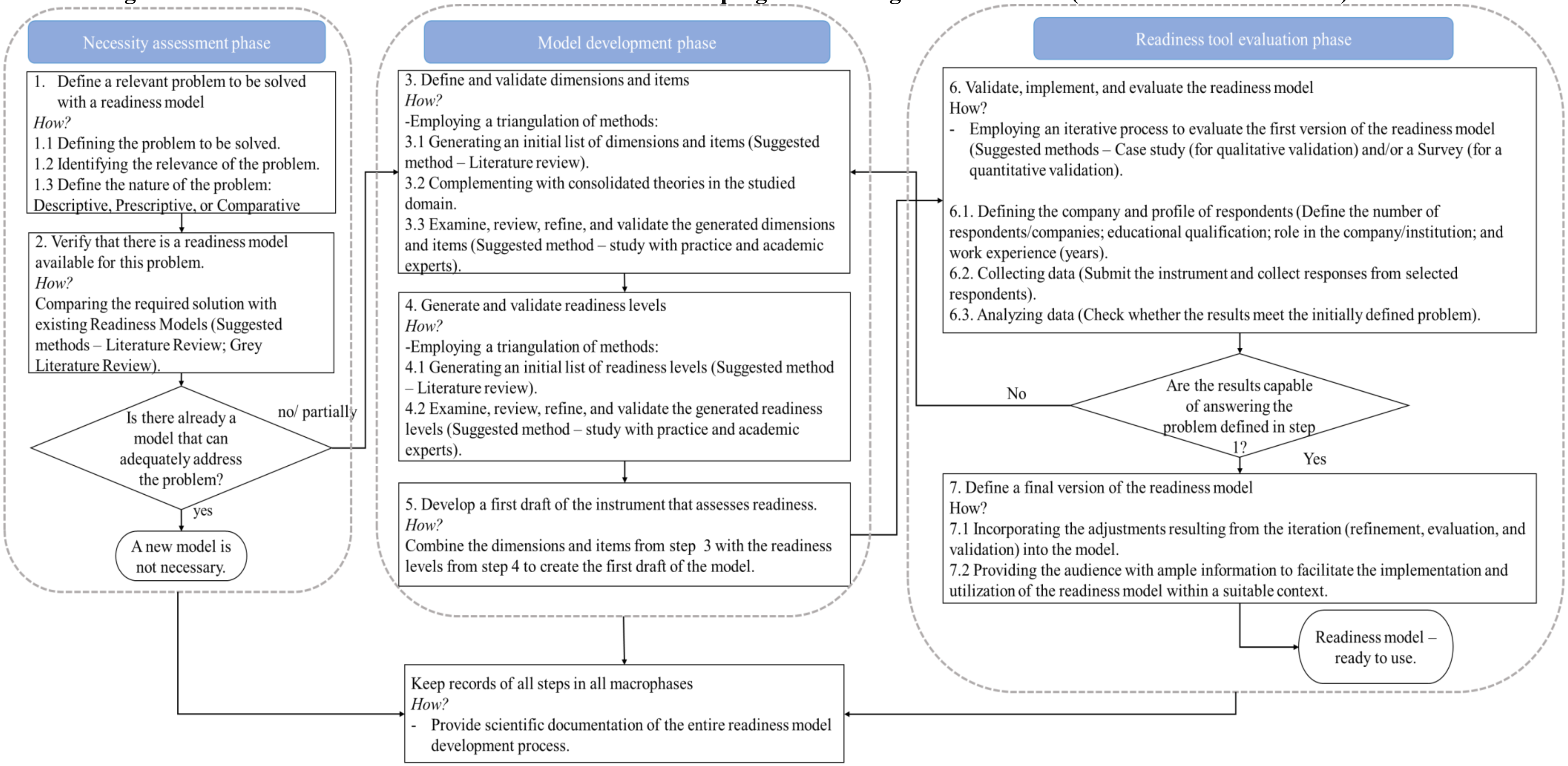
The initial version of the framework was proposed, which had the following primary characteristics: (i) three macrophases; (ii) seven steps; (iii) the key elements of readiness models (what to design: dimensions, items and, readiness levels); and (iv) the recommendation of methodological approaches considered suitable for the model development stages. These aspects were defined following the eight requirements for the development of readiness models that Becker, Knackstedt and Pöppelbuß (2009) previously established, and based on the 35 readiness models evaluated in our SLR.

6.4.2 Final Framework

In keeping with DSR guidelines, our framework follows an iterative process that integrates theoretical constructs and empirical insights, ensuring the artifact's utility and validity. By conducting a rigorous literature review with content analysis, and engaging with experts, we ensure that the developed framework is not merely a theoretical construct but a functional tool that can assist the development of readiness model for organizations assessing and enhancing their digital transformation readiness.

In summary, DSR provides a solid foundation for our research, offering a structured yet flexible approach essential to developing a standardized readiness assessment model tailored to the dynamic, complex landscape of Industry 4.0 and Operations and Supply Chain Management. Consequently, the framework's final iteration, as illustrated in Figure 6.5, was achieved through a series of refinements and expert validations.

Figure 6.5 - Framework: Reference architecture for developing RMs for digital innovations ("WHATs" and "HOWs")



Source: Author's own work.

Our framework is separated into three macro phases, as outlined below.

6.4.2.1 Macro phase 1: Necessity assessment phase

This initial phase determines the need for a new readiness model by defining the problem to be solved, evaluating existing solutions, and identifying gaps in the current literature and practice. It involves a critical examination of whether the existing models adequately address the problems organizations face in assessing their readiness for digital transformation.

Step 1 – Define a relevant problem to be solved with a Readiness Model

Steps 1.1 and 1.2 - Define the problem to be solved and the relevance of this problem

An artifact is suggested as a solution to a real-world issue in DSR. Models, according to Simon (1996) and Hevner *et al.* (2004), represent real-world situations with constructs. Consequently, a problem requiring a resolution must be identified and characterized in this initial phase. Formally, a problem is the gap between the current state of a system and the desired state (Hevner *et al.*, 2004). In the realm of this study in Operations and Supply Chain Management, the primary problem pertains to developing a model that transitions organizations from a state of unawareness about their readiness for digital innovations, which may include blockchain, big data, AI, and other Industry 4.0 technologies, to one where they possess precise knowledge of their readiness level and can subsequently progress to higher levels.

Before model creation, the researcher must define the projected application domain, usage conditions, and expected benefits (Requirement 6: Problem Definition) (Becker; Knackstedt; Pöppelbuß, 2009). At this point, therefore, it is necessary to define the characteristics of the problem under investigation. The characteristics established during this step will serve as a guide for the entire model construction process. It is crucial to provide precise details to ensure the creation of a model that accurately reflects the real-life context that the developers aim to investigate. An advantage of this specificity is the ability to meet to the user's desires in the final model, which can differ in terms of scope and purpose. Key factors to consider include the specific technology under evaluation, the level of robustness or simplicity of the readiness model, the organization's size and sector, and its location, among others.

For example, Vrchota and Pech (2019) state that managers wonder if they are ready for new global changes generated by advances in artificial intelligence, digitalization, robots, complexity, and network theory. As a result, the authors created the Index of Industry 4.0 (VPi4) model to help managers answer their concerns. They defined the problem by focusing on challenges in technology implementation, cost management, risk reduction, market competitiveness, and firms' digitalization journeys.

Some models may also be defined in a general manner, with greater details being established upon application. The benefit of these more generalized models is their adaptability to many circumstances. An inherent disadvantage is that tailoring the model to a particular context can be arduous and may overlook certain nuances of the examined situation. This is because the iterations in constructing each stage of the model were carried out without explicitly considering factors such as the specific industry and company size. Some models, such as those for manufacturing and Supply Chain industries (Bastos *et al.*, 2021; Demir *et al.*, 2023), are more generic, while others, such as those by Zoubek; Simon (2021), focus specifically on internal logistical activities. Defining benefits and application areas helps in setting parameters from problem representation to outcome analysis.

Lokuge *et al.* (2019) defined their problem as creating an organizational readiness model for digital innovation that was simple, generalizable, validated, robust, and allowed for practical and effective assessment. To address the shortcomings of current models, Pirola, Cimini and Pinto (2020) developed a model that would serve as a tool for SMEs wishing to evaluate their readiness before implementing the transition to smart manufacturing.

According to Requirement 5 (Identification of Problem relevance), the relevance of a DSR effort is evaluated about a constituent community, therefore the solutions proposed must address the challenges encountered by this community as well as the opportunities presented by the interaction of people, organizations, and information technology (Becker; Knackstedt; Pöppelbuß, 2009; Hevner *et al.*, 2004).

The problem of the unknown of readiness is significant, as a company that fails to implement a particular technology may abandon all future endeavors involving that technology while continuing to propagate a negative perception of it. This becomes even harder in Supply Chains, where companies are unable to maintain the same level of readiness and face communication difficulties. Lokuge *et al.* (2019) commented on the limited insights in research, the significant potential for innovation using digital technologies, and the risk of not innovating in competitive markets, demonstrating the relevance of developing the organizational readiness model for digital innovation that they proposed in their study. Pirola, Cimini and Pinto (2020) claim that the effective implementation of Industry 4.0 also includes SMEs, which play a key role in creating industrial value in many countries, hence establishing the model's relevance.

As mentioned earlier, enterprises face challenges in implementing the technologies they work with, increased expenses and risks, and pressure from highly competitive marketplaces. This community would value effective artifacts that facilitate the resolution of such problems.

Step 1.3 - Define the nature of the problem: Descriptive, Prescriptive, or Comparative

Descriptive models are suggested as a diagnostic tool and are used to represent and assess an organization's current state (De Bruin *et al.*, 2005). Every model is, by definition, a descriptive model since they are thought of as descriptions of how things are (Dresch; Lacerda; Antunes, 2015; March; Smith, 1995).

A prescriptive model shows a path to greater degrees of readiness or maturity and gives guidance and metrics for an organization (Bertassini *et al.*, 2022; Okongwu; Morimoto; Lauras, 2013; Reis; Mathias; De Oliveira, 2017; Röglinger; Pöppelbuß; Becker, 2012). As a result, if the developed model is prescriptive, an analysis of the organization's current readiness situation must be conducted, as well as a plan or a roadmap containing the guidelines and measures that the organization must follow to comply with all the requirements necessary to achieve the highest level of readiness for the adoption of the innovation under study.

According to de Bruin *et al.* (2005), a comparative model allows for benchmarking across industries or regions, and a model like this must be capable of comparing similar practices amongst firms to measure readiness/maturity in various sectors. De Bruin *et al.* (2005) go on to argue that, although these three kinds of models are considered distinct, they reflect the evolutionary stages of a model's life cycle; the explanations that follow are based on their argument. First, a model must be descriptive to provide a deeper understanding of the domain's current condition. This model may then become prescriptive, as only an in-depth understanding of the existing situation allows for significant, repeatable changes to be recommended and implemented. Finally, for a model to be used comparably, it must be applied across a broad range of businesses to collect sufficient data for a legitimate comparison.

In summary, an endeavor to comprehend the problem is necessary in this initial stage (Simon, 1996). During this stage, the researcher must gather an extensive amount of information to attain a comprehensive understanding of the subject's aspects, causes, and context (Dresch; Lacerda; Antunes, 2015). Determining whether the model will be descriptive, prescriptive, or comparative in characteristic is therefore necessary. Because all the artifact's features, expected performance, and operating needs may be designed based on this definition (Dresch; Lacerda; Antunes, 2015).

Step 2 – Verify if there is a readiness model available for this problem - Compare the required solution with existing readiness models

Hevner *et al.* (2004) claim that intentional artifacts are created to answer previously unsolved problems. As a result, once a problem has been recognized and characterized, it is necessary to determine whether a solution exists. The necessity to develop new readiness model must be justified. To do this, Becker, Knackstedt and Pöppelbuß (2009) advise that a comparison with existing models (Requirement 1) should be conducted. When comparing the desired solution with existing readiness models, it is possible to determine whether a solution already exists and identify weaknesses in the available models that must be addressed in the model to be produced.

Existing readiness models may be available in journals within the examined domain, enabling model comparison through a literature review. Literature reviews enables researchers to use current knowledge and consult other studies that address the same or related challenges (Dresch; Lacerda; Antunes, 2015). The available models in the literature are evaluated against pre-established criteria, and important points, such as research gaps, can be identified, as well as the current problems and limitations of these approaches.

Furthermore, models created by companies, such as consulting firms, can be found in gray literature. Models discovered in gray literature may not have been constructed with the same scientific and methodological rigor as those found in white literature. However, they may have been used across several companies, demonstrating their practical usefulness. Thus, these models can also be examined, as they may provide useful insights for developing a new readiness model with empirical and theoretical validity.

In cases where existing models are inadequate to solve the problem defined in step 1, or if an enhancement to the existing model is required, a completely new model, or a model that considers the recommendations of existing models while covering potential gaps, should be developed during macrophase 2. For instance, despite the presence of multiple readiness models for Industry 4.0 in the literature, (Monshizadeh *et al.*, 2023) recently introduced their industry 4.0 readiness model utilizing the fuzzy cognitive maps approach. When conducting a comparative analysis of the I4.0 readiness models found in the literature, the authors identified and discussed the fundamental constraints of each model, hence highlighting the differences between them.

If there is an existing model that fully fulfills the researcher's demands for solving the problem, it can be used, as was done in the study of Alcácer *et al.* (2021) and Denicolai, Zucchella and Magnani (2021), eliminating the need to create a new model.

6.4.2.2 Macro phase 2: Model Development phase

Upon establishing the necessity of a new model, this phase is dedicated to the systematic design and creation of the readiness assessment model. It involves defining the model's theoretical underpinnings, its constructs, and the methodological approach for its development. After this macro-phase, two key outputs should be generated: the readiness model, which must subsequently be evaluated, and the construction heuristic model. Construction heuristics, which emerge from the construction of artifacts, are one of Design Science's contributions to knowledge advancement (Dresch; Lacerda; Antunes, 2015).

Step 3 – Define and validate dimensions and items

Step 3.1, 3.2, and 3.3 - Employ a triangulation of methods for dimensions and items definition and validation

The model must accurately represent the technology, the organization, and the context into which it is inserted; hence, establishing the dimensions and items that will be used to evaluate the organization is a critical step. At this step, it is necessary to clearly describe the dimensions and items that represent the problem to be addressed by employing a readiness model. It is crucial to emphasize that both the identification and validation of these components are critical.

Although there is a specific requirement for artifact evaluation (Requirement 3) (Becker; Knackstedt; Pöppelbuß, 2009), this does not eliminate the need for partial evaluations of the outcomes to be carried out in each of the steps designed for developing models utilizing the DSR technique (Dresch; Lacerda; Antunes, 2015). As a result, we advocate iteratively evaluating the partial outcomes created at each level of the model to demonstrate that the artifact can be utilized to solve real-world problems (Dresch; Lacerda; Antunes, 2015; Tremblay; Hevner; Berndt, 2010).

As discussed in Section 6.4.1.1, the most common procedures for determining dimensions and items are literature reviews and expert interviews. Becker, Knackstedt and Pöppelbuß (2009) advocate that readiness models be constructed via an iterative technique, or, as Hevner *et al.* (2004) put it, as a search process. In our framework, we propose that each important stage of component definition be developed in this manner; in the case of step 3, the generated items and dimensions must be evaluated, reviewed, and refined to find the best solution while considering the parameters and constraints of the analyzed problem.

As the most used methodologies, we recommend conducting a literature review in the field of interest for a first inquiry and developing dimensions and items. Subsequently, the dimensions and items developed could potentially be complemented and strengthened by constructs that have previously been validated and drawn from established theories in the topic in issue. It is possible to employ theories as a lens to help researchers reach other features that are not necessarily covered by the examined literature, depending on the technology for which they are constructing their model.

In the context of this study, which addresses the readiness for adopting innovations using digital technologies in the field of Operations and Supply Chain Management, theories such as the TOE framework, is one theory that has been used to identify the factors impacting the adoption of technologies such as blockchain (Kajla *et al.*, 2023). It combines concepts about Technology, Organization, and Environment in which firms function. The Unified Theory of Acceptance and Use of Technology (UTAUT) incorporates constructs associated with Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions that can be used to evaluate the adoption of virtual reality, as per Huang (2023) and Khin and Kee (2022) researches. The Technology Acceptance Model (TAM) is another theory that has been employed in the context of technology. This model introduces constructs such as Perceived Ease of Use, Perceived Usefulness, and Behavioral Intention to Use, among others. For instance, Masood and Sonntag (2020) implemented this theory to evaluate the implementation of Industry 4.0 by SMEs.

Next, we propose a study with practice and academic experts so that these constructs can be examined, revised, and refined in terms of their true value in assessing the problem to be solved. Utilizing expert opinions proved to be a helpful strategy when confronted with uncertainty arising from technological innovations (Bokrantz *et al.*, 2017; Irannezhad *et al.*, 2021). With this, we have an iterative process in which elements and dimensions can be relocated, added, or excluded, as well as those that are not addressed in the literature or theories but are empirically relevant and added to the model. Using an iterative procedure and a triangulation of methods during each phase that requires the definition of an important component of the model prevents the model from being evaluated only when it is ready.

The examined readiness models, which employed expert validation of their dimensions and items, exhibited significant variation in the number of responses, ranging from a mere 2 to 30 experts. Saad, Bahadori and Jafarnejad (2021) employed a substantial number of experts, specifically 30 industrialists from various UK industrial SMEs. Lokuge *et al.* (2019) conducted a study including 9 experts who held roles equivalent to CIOs (chief information officers). As the authors are building a readiness model for digital innovation, we emphasize the expertise of the selected professionals in information technology-related roles.

For example, Pacchini *et al.* (2019) validated the findings of their literature review with four experts on the subject, one from academia (PhD in Operations Management and professor involved with I 4.0 research), one from industry (Mechanical Engineer with more than 20 years of experience in auto parts manufacturing, responsible for I 4.0 implementation in a Brazilian subsidiary of a large European autoparts producer)), one from Government (MSc in Information Systems and the I 4.0 coordinator at the Brazilian Ministry of Industrial Development and Trade) and one from an I 4.0 consulting company (PhD in Electrical Engineering and leading consultant for I 4.0 implementation at a large multinational consulting company with subsidiary in Brazil). Irannezhad *et al.* (2021) included a diverse group of professionals comprising of 5 experts on their panel. Instead of only having many experts, it is crucial to emphasize the significance of utilizing experts from different sectors, who possess significant expertise. These experts can offer diverse viewpoints on Industry 4.0 for the same study.

Furthermore, we emphasize the significance of the professionals' level of expertise and the duration of their experience with the technology being studied. For instance, Khan *et al.* (2021) conducted a study including 21 senior managers and decision-makers who had over a decade of experience and were knowledgeable about current technological trends. Wankhede and Vinodh (2023) suggested that it is beneficial to have experts with extensive experience of at least 10 years in top managerial roles as part of a five-member expert team.

When validating dimensions and items with experts, it is crucial to consider not only the quantity of experts involved, but also their positions and ensuring that they have direct interaction with the technology being analyzed. Additionally, we emphasize the significance of including experts from different backgrounds and sectors in the same research, including those from academia, industry, consulting firms, and government. This diverse group can offer distinct viewpoints on the dimensions and items of the model. We also emphasize the significance of the expert's experience with the technology under consideration. Based on the findings of reviewed studies, we suggest that individuals should have a minimum of 10 years of experience, particularly when the technology in question has been available on the market for a period. However, in the realm of Operations and Supply Chain Management, newer technologies like blockchain may not be accompanied by extensive professional experience. The strategy employed by Irannezhad *et al.* (2021) involved the recruitment of professionals with a minimum of ten years of expertise in the pharmaceutical sector and three years of competence in blockchain technologies.

In light of the aforementioned, as well as the revised readiness models and requirements 2 (iterative procedure), 3 (evaluation), and 4 (multimethodological procedure) proposed by Becker, Knackstedt and Pöppelbuß (2009), we have formulated the subsequent suggestion regarding the execution of this phase: use a mixed-method approach (combining qualitative methods and techniques) or multimethod triangulation (integrating different qualitative approaches and techniques) for the definition and validation of dimensions and items (Creswell; Creswell, 2018). In specific ways: (1) Conducting a literature review; (2) Supplementing with consolidated theories on the studied domain; and (3) Collaborating with academic and practical experts to refine and validate the generated dimensions and items.

In summary, the framework advocates a triangulated approach to ensure both conceptual rigor and practical relevance in defining and validating model components.

This triangulation integrates three complementary strategies: (i) an SLR to identify consolidated dimensions and items; (ii) the incorporation of established theoretical constructs to strengthen conceptual robustness; and (iii) iterative validation with academic and industry experts to guarantee applicability in real-world contexts. By combining these methods, the framework mitigates biases associated with relying on a single source and enhances the overall validity and reliability of the readiness model.

Step 4 – Generate and validate readiness levels

Step 4.1 and 4.2 - Employ a triangulation of methods for readiness levels generation and validation

After specifying the items and attributes of a model, readiness levels must be proposed. These levels must be designed following the items and dimensions in question, and they must correspond to categories or classes based on their degree of conformity. Normally, the team designing the model proposes these levels based on what the literature has done in this area.

It is crucial to carefully consider the quantity of readiness levels that need to be established. Having an excessive number of levels can complicate the transition between them. Felippes *et al.* (2022) stated that if a variable is too generic, its accurate assessment is difficult and if a level is too generic, a clear distinction between the levels of a dimension is jeopardized. A recommended strategy for creating levels is to ensure that there is a distinct and discernible shift or difference that signifies the transition from one level to the next.

The readiness models reviewed incorporate three to six readiness levels, with a majority utilizing five levels. Based on the existing literature on readiness models in digital innovation, we propose a range of three to six stages of readiness for model development.

As mentioned in Step 3, we recommend using iterative procedures to generate and validate model components. Hence, it is advisable to identify readiness levels in the literature and subsequently assess, improve, and validate the criteria that will categorize the organization into each of these levels with the assistance of experts possessing profound expertise in the model's domain. Pacchini *et al.* (2019) introduced a method for quantifying the level of readiness of an organization, drawing on existing literature, including the work of Lucato *et al.* (2019) and Pacchini *et al.* (2019) for calculating readiness. They also used the International Organization for Standardization

(ISO)/International Electrotechnical Commission (IEC) 15504-5 standard (good practices of software engineering) (ISO and ISO/IEC 15504-5, 2004) as a foundation to propose six levels of sequential and cumulative metrics to evaluate how well an organization is prepared to implement I4.0.

Bertassini *et al.* (2022), using the Fuzzy Inference System (FIS), propose a rule base (243 if-then rules) for categorizing an organization into readiness levels. The consequent linguistic term for each rule is defined by a panel of 6 experts in the field with in-depth knowledge of antecedent interactions.

At this point, we recommend that experts with extensive knowledge of the model's area, items, and dimensions assist in defining, refining, and validating the process by which these readiness levels are assigned, combining all possible scenarios for the model's items and dimensions.

Step 5 - Develop a first draft of the instrument that assesses readiness - Use the dimensions, items, and readiness levels to develop the instrument (questionnaire/checklist)

Once the items, dimensions, and readiness levels have been determined, the assessment instrument can be created. Thus, a first version of the instrument is created, with the items, dimensions, and readiness levels previously defined and validated.

How the instrument is written will influence the intricacies of its application in the next stage. If the items are more objective, the instrument can be a checklist in which respondents (units of analysis) must indicate whether that aspect is present or absent in their organization. If the items are more subjective, measurements must be developed. The instrument can be designed as a questionnaire, with respondents fitting their firm into a pre-determined alternative that best depicts their situation concerning the issues under consideration.

A Likert scale is a popular tool for measuring conceptual expressions, in which participants rate a series of assertions (Diamantopoulos; Winklhofer, 2001; Lassnig *et al.*, 2022). This is what Demir *et al.* (2023) explored in their study. They operationalized and quantified the elements gathered qualitatively during the literature review using a five-point Likert scale. Lassnig *et al.* (2022) devised a scale on which respondents could select one of six possibilities ranging from "completely agree" to "completely disagree". According to Diamantopoulos and Winklhofer (2001), having an even number of options forces the participant to choose one side of the solution.

In addition to being applicable in the real-world environment of an organization by developers (specialized researchers), the instrument can be designed to serve as a self-assessment tool. This is the case of Ramanathan and Samaranayake (2022) study, which aimed to create a user-friendly instrument that managers could use without resorting to sophisticated mathematical and statistical analysis. In an appendix form, the authors also included suggestions for steps that should be taken while conducting the self-assessment about each determinant, assisting with the evaluation.

Felippes *et al.* (2022) created the 3D-CUBE model, which allows for an assessment of the company's readiness through self-assessment or interview. According to these same authors, readiness or maturity models could become so complicated that professional judgment is required to interpret the outcomes following their implementation in organizations. In this regard, it is crucial to note that rigor does not imply the adoption of sophisticated methodologies (Dresch; Lacerda; Antunes, 2015). When working with DSR, rigor entails highlighting and justifying the techniques used to improve the reliability of the artifact and its outcomes about its intended use (Dresch; Lacerda; Antunes, 2015).

Since the instrument must be administered to professionals working in the companies being examined, the questionnaire's length must be considered, as overly long questionnaires may be more challenging for respondents to complete. For example, Bertassini *et al.* (2022) began with a list of 155 items to assess preparation for a culture oriented toward the circular economy. Regarding the questionnaire's length, they consulted specialists before constructing their instrument to determine which items would be most significant for the model. As a result, the final model had a shorter list (76) than the initial version (155). As a result, it is recommended that the instrument be designed to measure as much useful information as possible while being lean enough to be acceptable to the examined unit.

The next macro phase is to assess the instrument's suitability by combining these components simultaneously.

6.4.2.3 Macrophase 3: Readiness tool evaluation phase

The final phase encompasses the application and validation of the developed model. This involves evaluating the model's applicability in a real-world setting. This stage seeks to promote improvements, adjustments, and refinements to develop a model suitable for assessing an organization's readiness to embrace digital technologies.

Step 6 - Validate, implement, and evaluate the Readiness Model

After developing the first version of the complete instrument, it must be assessed to confirm that it is adequate for usage in practice. As discussed in Section 6.4.1.2, the Evaluation requisite (R3) states that the model's outputs, as well as its quality and efficacy, must be iteratively assessed using suitable scientific methodologies (Becker; Knackstedt; Pöppelbuß, 2009; Hevner *et al.*, 2004). This assessment may be carried out via an application in a real context, an iteration that can assess the model's applicability, support further adjustments and enhancements, and demonstrate that it is ready for use. This assessment will result in an artifact capable of being instantiated.

This validation can be conducted using either a qualitative or quantitative evaluation. During our SLR, we found that the readiness models were typically assessed qualitatively through case studies (Felippes *et al.*, 2022; Pirola; Cimini; Pinto, 2020; Zoubek; Simon, 2021) and quantitatively through surveys (Khin; Kee, 2022; Lokuge *et al.*, 2019; Vrchota; Pech, 2019). It is important to note that there are other validation techniques besides the two mentioned. However, as these two approaches were the most used in the Readiness Models analyzed, our recommendations for conducting step 6 will be based on the possibilities they offer.

During the model validation stage, the primary objective is to assess the accuracy of the proposed model in representing the aspects that impact organizational readiness. The primary aim of the model validation stage is to evaluate the accuracy of the proposed model in capturing the factors that affect organizational preparedness. This entails determining whether it can capture the critical factors that influence an organization's readiness to employ digitally innovative technologies. To ascertain whether the proposed model can effectively predict and explain organizational readiness, data collected through a survey or a case study would be used.

By employing a qualitative assessment, such as a case study, to validate the model, it is evident that the results obtained will primarily consist of qualitative information. This includes detailed descriptions, data interpretations, and context-specific insights derived from the organizations under study, regarding their readiness to embrace innovations with digital technologies. Therefore, the use of case studies enables a deeper, more contextual understanding of the factors that influence organizational readiness. It is feasible to investigate the extent to which organizational culture, leadership strategies, change management practices, and other variables influence the adoption of technologies in particular contexts. Lastly, the utilization of a more qualitative model evaluation approach enables the capture of nuances and complexities that may not be easily quantified. This encompasses factors such as individual motivations, organizational barriers, resistance to change, and other factors that can have a subtle yet significant impact on organizational readiness.

Conducting a validation survey will yield additional benefits for the study. Since the outcomes in this scenario are primarily quantitative, meaning they are based on numbers and statistics, it is feasible to gather data on the relationship between the components of the organizational readiness model, such as the correlations between variables. By using a representative sample and employing reliable data collection methods, it is possible to extend the validation results to a broader population. The ability to generalize the data enables the conclusions to be used more widely in similar organizational environments.

Thus, although survey validation provides generalizable quantitative insights into the relationships among the readiness model's elements, the case study provides a more in-depth, context-specific understanding of the factors that influence organizational preparedness. Therefore, the researcher must meticulously consider method selection at this stage to achieve their objectives regarding the artifact's validation and evaluation. Both methods have advantages and can be useful in comprehensive model validation. Combining these two methodologies provides for a more comprehensive and robust validation of the organizational readiness model. While the survey collects quantitative and generalizable data, the case study gives qualitative and contextual insights, resulting in a fuller and more accurate picture of organizational readiness to embrace Industry 4.0 technology.

Among the readiness models we examined, most studies that employed case studies for qualitative assessment used between one pilot case (Felippes *et al.*, 2022; Zoubek; Simon, 2021) and two cases (Pirola; Cimini; Pinto, 2020). These pilot applications assessed the model's feasibility in real-world scenarios, resulting in improvements and refinement to the subdimensions of the readiness analysis. Therefore, we suggest that doing one or two pilot cases is sufficient for qualitative validation of the model.

It is crucial to keep in consideration that the developed model is currently being validated to ensure its content and applicability, specifically its capacity to measure the proposed outcomes. The model validation stage concerns the adequacy of the proposed model, whereas the assessment of organizations' readiness involves applying this model to evaluate the level of readiness of specific organizations to adopt digital technology innovations.

Several of the studies reviewed do not conduct this validation through pilot cases and instead proceed directly to readiness assessment. Pacchini *et al.* (2019), Khan *et al.* (2021) and Saad, Bahadori and Jafarnejad (2021) performed well-conducted case studies to evaluate the readiness of the analyzed organizations, demonstrating how the proposed approach could be applied in real-world situations. This type of illustration is interesting because it enables not only the practical testing of the proposed model's usefulness but also the provision of valuable insights into the current level of readiness of the organizations under study. Additionally, it helps identify areas of both strength and weakness, which can inform intervention and development strategies.

Although this is a significant illustration, it is not the subject of our discussion in step 6 when we discuss the validation of the readiness model. The model can be used to assess the readiness of any organization in stage 3 (Decision), which involves determining whether to implement or reject a specific technological innovation (see Figure 6.1), if it has already been validated for its content and applicability.

For example, Pirola, Cimini and Pinto (2020) and Zoubek and Simon (2021) evaluate their models using pilot applications before applying their previously validated model to assess company readiness. Pirola, Cimini and Pinto (2020) assessed 20 manufacturing SMEs' readiness using the validated model and identified priorities for a successful journey to Industry 4.0. Zoubek and Simon (2021) tested their model on 29 industrial companies. However, this application is a topic for future phases; our investigation is limited to the validation of the readiness model.

Regarding the evaluated readiness models, most of those that utilized a quantitative survey evaluation initially carried out a pilot test, administering the instrument to a smaller group of participants. The objective of this pilot test is to evaluate the feasibility of the study, encompassing the operational aspects of data collecting, participants' acceptance of the instrument, and identification of any potential challenges that might arise during the implementation of the study on a broader scope.

Following the pilot test, the instrument is used on the entire sample to achieve a more comprehensive and representative understanding of the research target population. During this phase, hypotheses are examined, and representative samples lead to increased statistical accuracy. At this point, in addition to the researchers effectively assessing the variables identified in the research, new insights or issues may arise that necessitate further revisions. Even if the instrument was validated during the pre-test and pilot test, applying it to the entire sample allows for additional development of the instrument and the research model, ensuring the validity and reliability of the results.

For example, Lokuge *et al.* (2019) conducted a pilot survey analysis with 26 participants, which resulted in the insertion of certain explanatory remarks. The survey instrument was then distributed to a larger sample, and 378 respondents answered all of the survey's questions. Monshizadeh *et al.* (2023) ran a pilot test with ten responders to refine the results. They subsequently distributed the questionnaire to a broader sample, of which 257 people responded.

As we can see, there are different methods for validating the model, some simpler, such as qualitative assessment, and others more robust, such as assessment via survey. Each has both advantages and disadvantages. Simpler validation has the advantage of being more applicable and practical. More robust alternatives can reach higher levels of reliability.

Below, we discuss some of the key processes for performing model validation using the two methodologies we discussed earlier.

Step 6.1 and 6.2 – Define the company and profile of respondents and Collect data (Validation and Implementation)

The first step in conducting the pilot application is to define the company (or companies) where the instrument will be tested and who the respondents will be. As a result, it will be necessary to specify the number of respondents, the sample size of companies, educational qualifications, role in the company/institution, and years of work experience.

The selection of companies and respondents for validating the readiness model can differ based on the research objectives and the chosen methodological methodology. Nevertheless, it is possible to provide some general suggestions. It is important to consider companies and respondents (experts) with diverse experience. While it is beneficial to include organizations with substantial expertise in the technology being examined, it is also crucial to include companies at all levels of readiness. This enables a direct comparison between firms that are in the early stages of exploring new technologies and those that have already used them extensively. In addition, companies that have not yet begun implementing the technology but are interested in adopting it can offer valuable insights regarding the difficulties encountered in completing the questionnaire and the challenges they face with the technology. These insights may lead to significant adjustments in the final model.

Furthermore, it is important that the sample accurately reflects the sector or sectors under investigation. By incorporating a diverse range of organizations with varying sizes, sectors, and geographic locations, a clearer picture of each organization's readiness to embrace the innovation being examined can be obtained.

If the researcher decides to validate the readiness model with a qualitative assessment with a case study, he must select one or more organizations. As previously stated, one or two pilot examples are sufficient to validate the readiness models qualitatively. In addition to selecting one or more organizations based on earlier recommendations, it will be necessary to define the respondents' professional profile, functional area, number of respondents per functional area, and their experience.

For example, Pirola, Cimini and Pinto (2020) validated their approach using two pilot case studies. These two organizations were chosen based on their major characteristics and propensity for innovation, with the first aiming to improve the intelligence of its goods and the second to expand the digitization of its internal operations. Given these characteristics, these two companies could provide critical feedback on the model being developed. This validation phase was carried out by two experienced researchers, and the respondents were innovation managers in charge of Industry 4.0 pilot projects within their organizations during the last three years.

As a result, we recommend that both companies and respondents be selected based on their previous experience and propensity for innovation, so that they have feasible possibilities to provide meaningful feedback and insights about the model, enabling for its advancement. Companies and respondents who have not yet dealt with technology should report on the challenges they encountered in responding to the questionnaire, the time it took to complete it, their comprehension of the language and technical words used, and their primary critiques, among other factors. This vision is crucial as once validated, the model will be used to assess the readiness of firms that have not yet begun the process of integrating the technology in question.

Regarding the survey approach, Monshizadeh *et al.* (2023) conducted the pilot test of the questionnaire in person, and ten people among senior experts and managers in the Automotive industry participated. The authors subsequently implemented the instrument on a larger sample, consisting of 257 completed questionnaires. The research was conducted with the participation of professionals from a variety of automotive industry departments, including senior managers, senior experts, and junior experts.

Lokuge *et al.* (2019) did a pilot test with 26 senior IT managers who attended a monthly CIO business seminar series held by this article's authors. These experts reviewed the instrument and assisted in drafting explanatory statements. To apply the instrument to a broader sample, the researchers verified that all participating businesses were large and representative of all industry sectors. 378 people completed the questionnaire. Some of the criteria for selecting companies and respondents included the following: the organization had a dedicated CIO/CTO and a team of IT staff that managed the IT portfolio, the organization had used a portfolio of technologies for the previous 5 years, documentation of the IT roadmap since the implementation of the enterprise system was available, and the CIO had been in the position for at least 6 months at the time of data collection.

The pilot experiments in the revised models involved 10 to 50 respondents, while the survey instrument was administered to 110 to 409 respondents. Therefore, we suggest that surveys that involve validation employ enough respondents from these ranges. Nevertheless, we suggest that the researchers' objectives be considered when defining these parameters, and that specific and consolidated literature be considered. For more information on performing case studies, we suggest Eisenhardt (1989) and Yin (2018). For scale development, validation, and survey execution we recommend Menor and Roth (2007) and Forza (2002).

Step 6.3 – Analyze data (post-use evaluation)

As stated by Dresch, Lacerda and Antunes (2015), artifacts resulting from design-based research need to demonstrate their ability to accomplish the intended objectives, meaning that they must fully serve their function. Hence, in this stage, it is imperative to verify if the outcomes derived from the preliminary implementation align with the solution to the problem identified in step 1. It is necessary to evaluate whether the outcomes align with the problem that was initially articulated. At this point, the researcher needs to closely monitor and quantify the behavior of the artifact (model) as it tackles the problem (Dresch; Lacerda; Antunes, 2015). To accomplish this, it is important to assess the features and requirements that were established in step 1, pertaining to the understanding of the problem, and then compare them with the reported results to determine the level of compliance with these metrics (Dresch; Lacerda; Antunes, 2015).

If the model indicates an appropriate response to the requirements outlined in step 1, you may go to step 6.4 for the ultimate refinement to the model. Nevertheless, if the model fails to meet the specific requirements for its intended use, the researcher must identify the stages where the failures potentially occurred (Dresch; Lacerda; Antunes, 2015). As a result, once the stage at which the failure occurred has been discovered, it is recommended that the research be restarted at that point.

Step 7 – Define a final version of the Readiness Model

At this point, it is possible to assert that the artifact has fulfilled the essential criteria required for its intended use. The emergence of enhancements, corrections, and adjustments is an inevitable consequence of the iterative evaluation process outlined in steps 6.1 and 6.2. Consequently, these enhancements must be integrated into the model during this stage.

For instance, the pilot cases carried out by Pirola, Cimini and Pinto (2020) yielded significant feedback regarding the structure and substance of his model. The respondents expressed a favorable assessment of the selected aspects and suggested further inquiries to broaden the model's range. Consequently, the model was modified to incorporate additional relevant inquiries into the human element and the requisite levels of competence in Industry 4.0. In the Lokuge *et al.* (2019) study, the survey's pilot test led to the inclusion of additional explanatory statements. There was a question on whether the propensity to innovate was associated with the company or the individual who participated in the survey. A new assessment was included, providing instructions to respondents as follows: “This survey measures your organization's innovation readiness.”

Once researchers have integrated the improvements identified during the evaluation phase into the model, they should furnish the audience with sufficient information to enable the implementation and utilization of the readiness model in an appropriate context, as suggested by Becker, Knackstedt and Pöppelbuß (2009) requisite 7 (Targeted presentation of results). As previously stated in Topic 6.4.1.2, it is crucial to give the intended audience extensive information to help them effectively implement and utilize the described artifact in a suitable context. This will enable professionals to fully explore the advantages offered by the artifact and allow researchers to develop a comprehensive knowledge base for future expansion and evaluation (Hevner *et al.*, 2004).

To effectively disseminate the results of their research (requisite 7- Targeted presentation of results), researchers may generate a report that serves as a record of their findings. The report is required to provide a synthesis of the data that has been compiled, emphasizing the primary points and conclusions of the research. This approach enables stakeholders, managers, and other interested parties to receive research findings in a manner that is both comprehensible and easy to understand. Hence, the report is a critical component of the model development process, as it converts raw data into usable, applicable information, which is advantageous to both researchers and decision-makers who use the results.

There are two resulting outputs from this process. The first output is the properly evaluated artifact, which is a readiness assessment model that is suitable to be released for instantiation. The second result involves formalizing contingency heuristics, which the researcher will use to elucidate the constraints of the artifact and its conditions of use. Specifically, it will examine the artifact's interaction with the external environment in which it operates, as specified during the problem-understanding phase (Dresch; Lacerda; Antunes, 2015).

The ready-to-use approach may be used in real-world scenarios to evaluate an organization's preparedness to embrace digital technology innovation. In this example, the input is data about the investigated organization, which will respond to the questionnaire by proving how well it can meet the instrument's specified items. The result would be the company's level of readiness or preparation to implement a certain innovation.

Furthermore, we emphasize another requisite for developing models using DSR, the scientific documentation (R8). Researchers must offer complete documentation of the model creation process (from the beginning), since this provides Design Science Researchers with a solid basis of knowledge for future study expansions (Hevner *et al.*, 2004). This record promotes transparency in the research method and helps validate the results' credibility by documenting the development process and the analysis of the data. This is a critical step that functions as a historical record of the research conducted, enabling future comparisons or the replication of the study.

6.5 Artifact Demonstration

Evaluating developed artifacts is a fundamental aspect of DSR (Hevner *et al.*, 2004; March; Smith, 1995; Venable; Pries-Heje; Baskerville, 2016). For the framework proposed in this study, the primary validation challenge is that it must occur before any actual implementation (Wieringa, 2014), i.e., the framework has not yet been applied to build a readiness model for a specific technology. Since realistic implementation is not yet feasible, we followed Wieringa (2014) recommendation that validation can rely on simulated implementation within the DSR domain to assess artifact consistency.

We therefore adopted the Framework for Evaluation in Design Science Research (FEDS) proposed by Venable, Pries-Heje and Baskerville (2016), which guides the definition of evaluation objectives, selection of an evaluation strategy, identification of properties to be assessed, and design of the evaluation episode. Based on these principles, we conducted an ex-ante, artificial evaluation through a conceptual simulation using the TradeLens blockchain adoption case, aiming to demonstrate the framework's utility, applicability, and completeness prior to real-world use. The four FEDS stages are presented below.

6.5.1 Define the evaluation objectives (FEDS - Stage 1)

The evaluation objectives are: (i) to verify whether the proposed framework is useful and applicable for guiding the development of readiness models; (ii) to assess its completeness regarding the essential components identified in the literature; and (iii) to confirm its logical coherence across stages. The properties operationalizing these objectives are defined in Stage 3 (Section 6.5.3).

6.5.2 Select the evaluation strategy (FEDS - Stage 2)

Venable, Pries-Heje and Baskerville (2016) propose a taxonomy for artifact evaluation based on two dimensions: ex-ante vs. ex-post (timing — before or after implementation) and artificial vs. naturalistic (context — simulated or real-world). These distinctions align with earlier frameworks: Wieringa (2014) differentiates pre- and post-implementation evaluations, and Peffers *et al.* (2007) recognize that the Demonstration stage in DSR can be conducted through experimentation, simulation, case study, or other appropriate activities. Simulation, in this context, is understood broadly, encompassing not only computational models but also plausible illustrative scenarios that enable verification of an artifact's applicability.

Based on these principles, we opted for an ex-ante, artificial evaluation through a conceptual simulation, using the TradeLens case as the scenario. TradeLens is widely documented in the literature as a landmark initiative for blockchain technology (BT) adoption in Supply Chains, whose discontinuation was attributed partly to the ecosystem's lack of readiness, making it a particularly relevant and plausible scenario for assessing the framework's applicability and logical coherence prior to real-world implementation.

6.5.3 Determine the properties to be evaluated (FEDS - Stage 3)

According to Prat, Comyn-Wattiau and Akoka (2014), artifact evaluation in DSR involves two central questions: what to evaluate (criteria) and how to evaluate (methods). At this stage, we address the first question by defining the essential properties that must be assessed to verify whether the objectives established in Stage 1 have been achieved. As suggested by Hevner *et al.* (2004) and Venable, Pries-Heje and Baskerville (2016), these properties should reflect relevant quality attributes of the artifact, such as utility, completeness, and coherence.

Table 6.3 presents the selected properties and their operational definitions.

Table 6.3 - Properties evaluated in the artifact demonstration

Criteria	Definition
Utility/Applicability	The framework's ability to guide the development of RMs appropriate to the technological domain (e.g., blockchain in OSCM).
Completeness	Coverage of the essential elements required for building RMs: dimensions, items, levels, and procedures.
Logical Coherence	Logical sequencing of stages, with well-defined inputs and outputs and absence of contradictions.

Source: Author's own work.

6.5.4 Design the evaluation episodes (FEDS - Stage 4)

This stage describes how the evaluation was conducted. The episode was designed as an ex-ante, artificial evaluation following the FEDS framework (Venable; Pries-Heje; Baskerville, 2016), with the purpose of demonstrating, prior to any real implementation, whether the framework can effectively guide the development of a readiness model that is useful, complete, and logically coherent within the blockchain domain in Operations and Supply Chain Management. We performed a conceptual simulation of the framework's application, assuming a scenario prior to the launch of the TradeLens initiative. Publicly available information about the TradeLens outcome was used solely for plausibility checks, not as a starting point for problem definition, consistent with ex-ante evaluation practice (Peffers *et al.*, 2007; Wieringa, 2014).

In the following, we present the application of the three macro-phases and their respective steps to the TradeLens case.

Macro phase 1: Necessity assessment

Objective: Justify the need for a new Readiness Model

Step 1 – Define a relevant problem to be solved with a readiness model

Problem definition:

"How should a readiness model be structured and applied to assess the readiness of organizations within the TradeLens ecosystem for blockchain adoption, in order to support strategic decisions such as joining the consortium, integrating data, and establishing governance for information sharing?"

The goal is to address the gap between the current state (lack of knowledge about the ecosystem's readiness level) and the desired state (clear understanding of readiness to support informed decisions on technology adoption). This will be achieved through the development and application of readiness model capable of measuring and classifying readiness levels, providing actionable insights for strategic decisions such as consortium participation, data integration, and governance.

Regarding consortium participation, as highlighted by Rotem Hershko (Head of Business Platforms at A.P. Moller – Maersk): "Unfortunately, while we successfully developed a viable platform, the need for full global industry collaboration has not been achieved" (Kjærgaard-Winther, 2022). This statement underscores that broad consortium adoption is a critical condition for the viability of blockchain-based platforms. The successful implementation of blockchain in Supply Chains depends on the active engagement of a network of interconnected firms (Chavalala *et al.*, 2024), and restricted adoption by key Supply Chain stakeholders significantly constrained TradeLens's scalability and effectiveness (Moraes *et al.*, 2025a).

Regarding data integration, TradeLens was designed to enable "seamless, secure sharing of real-time, actionable Supply Chain information across all parties" (IBM & GTD Solution, *[S.d.]*). Such interoperability is a prerequisite for platform value delivery. However, convincing partners to share data is a significant challenge, primarily due to confidentiality concerns when sharing private information with potential competitors (Galvez; Mejuto; Simal-Gandara, 2018; Wang *et al.*, 2019), and research confirms these concerns became major obstacles to TradeLens adoption (Najati, 2025). The readiness model must therefore evaluate not only technological capabilities but also internal policies and governance mechanisms that enable secure data integration.

Regarding governance, in the context of TradeLens this encompasses strategic (off-chain), technological (on-chain), and interoperability mechanisms as essential components for managing a blockchain-based platform ecosystem (Jovanovic *et al.*, 2022). Evidence from the case confirms that "a lack of stakeholder engagement, unclear governance, and confidentiality concerns are major obstacles," and that blockchain projects must adopt "a holistic approach, with transparent governance, encourage collaboration, guarantee interoperability and invest in data security" (Najati, 2025). The readiness model should therefore include governance capabilities such as decision rights, compliance mechanisms, and conflict resolution processes.

Step 2. Verify if there is a Readiness Model available for this problem

This step aims to determine whether an existing readiness model can address the defined problem. In this demonstration, we rely on the SLR previously conducted in this research, which examined readiness models for adopting digital technologies in Operations and Supply Chain Management. Although the review was not exclusively focused on blockchain, it included studies addressing organizational readiness for blockchain adoption. The findings indicate that no comprehensive model exists that adequately supports the strategic decisions essential for the TradeLens case, such as joining a consortium, integrating data, and establishing governance for information sharing. This gap justifies the development of a new model.

Macro phase 2: Model Development

Objective: Develop the model components

Step 3 – Define and validate dimensions and items

This step identifies the key dimensions and items that will structure the readiness model, guided by two principles: (i) alignment with the literature on blockchain adoption and Operations and Supply Chain Management, and (ii) relevance to the strategic decisions identified in the TradeLens case: joining a consortium, integrating data, and establishing governance for information sharing.

Recommended methods:

a) **SLR:** Searches in Scopus and WoS using keywords such as readiness model, Maturity Model, blockchain adoption, and Operations and Supply Chain Management, with inclusion and exclusion criteria ensuring selection of peer-reviewed studies. Common dimensions and indicators extracted from these studies would inform the initial structure of the readiness model;
b) **Consolidated theories:** We recommend applying the Technology-Organization-Environment (TOE) framework (Tornatzky; Fleischer; Chakrabarti, 1990), which provides a comprehensive structure encompassing Technological, Organizational, and Environmental (external) factors widely used in technology adoption research;
c) **Expert input:** Dimensions and items should be validated through interviews or focus groups with experts with direct experience in blockchain-based Supply Chain initiatives, including academics specializing in Operations and Supply Chain Management and blockchain adoption, and practitioners, such as senior managers or decision-makers from ports, shipping lines, freight forwarders, and customs authorities involved in TradeLens or similar platforms, with knowledge of consortium governance, data integration, and regulatory compliance.

Table 6.4 presents an illustrative set of TOE-based dimensions and example items derived from blockchain adoption literature.

Table 6.4 - Dimensions (TOE-based) and Example Items

Dimension	Example Items (Constructs)	References
Technological Readiness	Availability of tools for cyber-physical integration.	(Gonczol *et al.*, 2020; Kurpjuweit *et al.*, 2021; Moraes *et al.*, 2025b).
	Infrastructure for interoperability.	(Chang; Iakovou; Shi, 2020; Moraes *et al.*, 2025b).
	Security infrastructure.	(Alam Khan *et al.*, 2020).
Organizational Readiness	Clear organizational policies for blockchain adoption.	(Farooque *et al.*, 2020).
	Governance practices for collaborative ecosystems.	(De Filippi; Mannan; Reijers, 2020).
	Top management support.	(Kouhizadeh; Saberi; Sarkis, 2021; Moraes *et al.*, 2025a; Nayak; Dhaigude, 2019).
Environmental Readiness	Collaboration among SC partners.	(Hastig; Sodhi, 2020; Morkunas; Paschen; Boon, 2019).
	Government incentives for blockchain adoption.	(Clohessy; Acton, 2019; Wang *et al.*, 2019).

Dimension	Example Items (Constructs)	References
	Compliance and agreement mechanisms among partners.	(Gonczol *et al.*, 2020).

Source: Author's own work.

The TOE framework ensures that readiness assessment covers the main determinants of technology adoption, while the selected items reflect the specific requisites and challenges of blockchain ecosystems such as TradeLens.

Step 4 – Generate and validate readiness levels

This step establishes a progressive scale that enables organizations to be classified according to their preparedness for blockchain adoption.

Recommended methods:

a) **Literature Review:** Conduct a review of existing readiness and Maturity Models to identify common structures and best practices for level definitions. To define readiness levels, we suggest using the logic of the Capability Maturity Model (CMM) (Paulk *et al.*, 1993) as a reference;

b) **Expert Evaluation:** Validate and refine the proposed levels through interviews or focus groups with academics (specialists in Operations and Supply Chain Management and blockchain) and practitioners (managers from ports, carriers, and logistics firms familiar with collaborative ecosystems).

To evaluate organizational readiness for blockchain adoption in the TradeLens context, we adapted the staged logic of the CMM (Paulk *et al.*, 1993). While CMM was originally designed for software process maturity, its progressive structure provides a robust foundation for readiness assessment. We reinterpreted the five original maturity levels (Initial, Repeatable, Defined, Managed, and Optimizing) into readiness-oriented stages and introduced an additional Level 0 ("Absent") to capture organizations with no awareness or initiatives related to blockchain. The resulting six-level scale (Absent, Aware, Exploring, Preparing, Integrating, and Leading) represents a clear progression from no readiness to advanced preparedness, consistent across the TOE dimensions and aligned with the strategic decisions identified in Step 1. Table 6.5 presents the adapted readiness levels and their corresponding definitions.

Table 6.5 - Adapted Readiness Levels for TradeLens

Readiness levels	Description
0 Absent	The organization has no awareness or initiatives related to blockchain; no resources allocated; no governance or compliance considerations.
1 Aware	Initial awareness of blockchain exists, but practices are ad hoc; no formal governance or compliance; collaboration is absent or minimal.
2 Exploring	Basic practices start to emerge and can be repeated; experimental initiatives underway; informal governance; limited digital integration; partial compliance; reactive collaboration.
3 Preparing	Policies and processes are formalized; governance structure established; technological capabilities implemented for key processes; regulatory compliance ensured; collaboration agreements in place.
4 Integrating	Processes standardized and monitored using metrics; active management of security and compliance; interoperability achieved with main partners; governance committees operational; structured stakeholder engagement.
5 Leading	Maximum readiness: continuous improvement based on data; advanced automation and interoperability; proactive governance and risk management; strong collaboration across the ecosystem; alignment with regulatory and industry initiatives.

Source: Author's own work.

Step 5 - Develop a first draft of the instrument that assesses readiness

This step aims to combine the dimensions defined in Step 3 and the readiness levels established in Step 4 into a structured assessment instrument, such as a questionnaire or checklist, that can be used to diagnose organizational readiness in the context of TradeLens. The instrument should translate conceptual items into measurable questions aligned with the readiness scale.

We recommend structuring the instrument as a questionnaire. For each item defined in Step 3, it is necessary to establish an evaluation scale that measures the degree of implementation or presence of the practice within the organization. To achieve this, we propose an Implementation Scale with five levels (item-levels):

1 = Not implemented

2 = Planned

3 = Partially implemented

4 = Fully implemented

5 = Continuously improved

This scale provides a clear, progressive measure of readiness, enabling organizations to be consistently assessed across all dimensions of the model.

After evaluating each item using the implementation scale, organizations should apply aggregation rules to calculate dimension scores. Subsequently, readiness level mapping rules should be defined to convert these dimension scores into an overall readiness level, as recommended by the framework. Table 6.6 provides an example of how this model's structure could be organized.

Table 6.6 - Illustrative Outline of the Model's Initial Draft

Dimension	Item (Question)	Implementation Scale (1–5)	Dimension scores	Organization Final Readiness Level (0–5)
Technological Readiness	Does your organization have tools for cyber-physical integration?	1–5	Calculate, based on the aggregation rules for dimension scores	Calculate, based on the readiness level mapping rules
	Does your organization have infrastructure for interoperability?	1–5		
	Is security infrastructure implemented and monitored?	1–5		
Organizational Readiness	Are there clear organizational policies to operate in collaborative ecosystems?	1–5	Calculate, based on the aggregation rules for dimension scores	
	Are governance practices established for collaborative ecosystems?	1–5		
	Is top management actively supporting initiatives in the TradeLens context?	1–5		
Environmental Readiness	Does your organization collaborate actively with SC partners?	1–5	Calculate, based on the aggregation rules for dimension scores	
	Does your organization leverage or is prepared to leverage government incentives related to this context?	1–5		
	Are compliance and agreement mechanisms in place among partners?	1–5		

Source: Author's own work.

Macrophase 3: Readiness tool evaluation

Step 6 - Validate, implement, and evaluate the Readiness Model

This step aims to verify whether the readiness instrument effectively measures organizational preparedness and provides actionable insights for strategic decisions in the TradeLens context. The evaluation should confirm the instrument's clarity, relevance, and practical utility before its full implementation.

Recommended methods:

Following the framework presented in Figure 6.5, this step may be conducted using a qualitative approach, a quantitative approach, or a combination of both, depending on the evaluation purpose, the stage of development of the readiness instrument, data availability, and access to stakeholders within the TradeLens ecosystem. Qualitative validation is particularly useful for assessing clarity, relevance, usability, and practical applicability, whereas quantitative validation supports the assessment of reliability and validity across a broader sample.

a) **Qualitative validation through case study:** Apply the instrument in selected organizations within the TradeLens ecosystem (e.g., ports, carriers, customs authorities). Collect feedback via interviews and workshops to assess whether the instrument supports decision-making and identify areas for refinement;

b) **Quantitative validation through survey:** Distribute the instrument to a broader sample of ecosystem participants to test reliability and validity using statistical techniques.

How this could be conducted in the TradeLens context:

a) Define a representative sample of stakeholders (shipping lines, port operators, customs agencies);
b) Administer the questionnaire developed in Step 5 to evaluate readiness across the TOE dimensions;
c) Analyze whether the results align with expectations (e.g., organizations with advanced IT capabilities scoring higher in Technological Readiness);
d) If inconsistencies or gaps are identified, return to previous steps to refine dimensions, items, or readiness levels, following the iterative logic recommended by the framework.

Step 7 – Define a final version of the Readiness Model

This step refines the readiness model based on validation results or confirms its adequacy if it meets expectations, delivering a robust and actionable model for assessing organizational readiness in the TradeLens context.

How this could be conducted:

- Analyze validation results from Step 6 to determine whether the instrument accurately measures readiness and produces meaningful classifications;
- Iterative refinement: If gaps or inconsistencies are identified, such as unclear items, missing factors, or misaligned readiness levels, return to Step 3 (dimensions and items), Step 4 (readiness levels), or Step 5 (instrument design) for adjustments. For example, if organizations with advanced IT capabilities score low in Technological Readiness, this signals a misalignment requiring revised indicators;
- Confirmation: If the instrument performs as expected, document the validation outcomes and confirm the model for deployment across the ecosystem.

In this demonstration, full validation is not executed but illustrated conceptually. The simulation addresses the three evaluation objectives established in Section 6.5.1. Regarding utility and applicability, the exercise shows that the framework can guide the structured development of readiness model, including dimensions, readiness levels, and an assessment instrument, aligned with the technological domain. Regarding completeness, all essential components identified in the literature are incorporated: dimensions, items, levels, methodological procedures, and evaluation steps. Regarding logical coherence, the sequence of steps follows a clear and rational flow, with well-defined inputs and outputs and no contradictions across phases. Although this is not an empirical validation, the demonstration corroborates the framework's potential as a reference architecture for future research and practical applications.

6.6 Conclusions

This section presents the main conclusions of the study, summarizing the proposed framework, its theoretical and practical contributions, as well as its limitations and future research directions.

6.6.1 Final Remarks

This study developed a framework that serves as a reference architecture for Operations and Supply Chain Management researchers to create organizational readiness models for digital technology adoption, following a well-substantiated sequence of procedures and methodological decisions. It is important to emphasize that the artifact is not itself a readiness assessment model, it guides the development of such models.

The framework was built through an SLR of 35 readiness models, analyzed against the structural criteria of Caiado *et al.* (2021) and the eight DSR requisites of Becker, Knackstedt and Pöppelbuß (2009). The iterative refinement process with ten experts produced significant changes to the initial version, including improvements to the artifact's layout, adjustments to the sequence of phases, and, most importantly, a transition from a more generic framework to one with stronger readiness-specific orientation. Two rounds of focus groups confirmed the final version's clarity, usability, and logical coherence. An ex-ante conceptual simulation using the TradeLens blockchain case further demonstrated the framework's applicability, completeness, and coherence prior to real-world instantiation.

The results contribute to a deeper and more critical understanding of existing organizational readiness models for digital innovation adoption, grounded in robust DSR principles. The framework integrates essential structural elements of readiness models with methodological rigor, reflecting expert consensus on its usefulness and relevance for future Operations and Supply Chain Management applications.

By consolidating the common structure and methods found across 35 readiness models and embedding DSR principles into a reference architecture, the framework moves the field toward greater standardization, comparability, and reproducibility of readiness model design. The ex-ante simulation in the TradeLens context further showcases how the framework can inform ecosystem-level decisions in the adoption of emerging digital technologies such as blockchain.

From a managerial perspective, the framework offers a structured roadmap for assessing organizational preparedness before committing resources to emerging technologies. By clearly identifying gaps (whether in technology, governance, or collaboration) managers can make informed decisions, avoid unnecessary costs, and reduce the risk of failed implementations. In blockchain initiatives such as TradeLens, the framework could guide decisions on consortium participation, data-sharing policies, and partner alignment. It also supports the creation of targeted capability roadmaps, allowing managers to prioritize interventions such as cybersecurity improvements, workforce upskilling, and compliance measures. By prescribing dimensions, items, and readiness levels, the framework facilitates the development of indicators that connect strategic intent to operational execution, enabling transparent monitoring and continuous improvement.

From a theoretical perspective, the framework advances the literature by consolidating a design vocabulary for readiness models and aligning their construction with DSR principles. By synthesizing common components (dimensions, items, levels, and methodological procedures) it provides a basis for cumulative knowledge, making artifacts comparable, auditable, and extendable. The multi-method approach operationalizes the rigor–relevance balance in readiness model research, while the conceptual simulation clarifies how to evaluate utility, completeness, and logical coherence prior to naturalistic instantiation. Although the TradeLens illustration focuses on blockchain, the framework's structure is technology-agnostic, inviting replications across different technologies (e.g., IoT, AI, digital twins) and contexts (e.g., SMEs, large multinationals).

6.6.2 Limitations and future research

Our research, like any other study, has its limitations. These constraints may initially limit the generalizability of the results, as we employed experts from a specific context, namely Operations and Supply Chain Management. Consequently, the results may be limited when applied to different organizational contexts or research areas. Another limitation concerns the empirical validation of the framework. Although the framework was validated by experts and complemented by an ex-ante conceptual simulation to ensure logical consistency, this artificial scenario does not replace real-world application. The simulation, based on the TradeLens case, assessed the framework's applicability, completeness, and coherence by illustrating how it would guide the development of a readiness model, including the definition of dimensions, readiness levels, and an assessment instrument aligned with the technological domain. While this approach provided evidence of potential effectiveness, further empirical studies are necessary to confirm its practical utility.

To address these limitations, future studies may broaden the sample of experts to include individuals with diverse viewpoints and experiences across various organizational contexts. Furthermore, given the primary goal of our study, future research can build on our framework to create models for assessing organizational readiness for adopting digital innovations. Using our framework as a foundation, researchers will be able to expand and adapt it to different technologies and employ a variety of empirical validation methodologies. This will help advance the Operations and Supply Chain Management field by promoting best practices and informed decisions when implementing digital technologies.

7 FROM READINESS TO ADOPTION: A FUZZY-BASED ASSESSMENT MODEL FOR BLOCKCHAIN TECHNOLOGY IN SUPPLY CHAIN CONTEXTS

This chapter focuses on the design, development, and evaluation of an organizational readiness assessment artifact for blockchain adoption in supply chain networks. Following a Design Science Research approach, the study operationalizes readiness conditions, develops an interpretable fuzzy-logic-based aggregation mechanism, and evaluates the artifact through expert assessment and a pilot application. The chapter delivers a validated, decision-oriented readiness instrument for blockchain adoption.

7.1 Introduction

Blockchain technology (BT) has been widely discussed as a promising enabler for supply chain (SC) transparency, traceability, and trustworthy data sharing across organizational boundaries (Chang; Chen; Lu, 2019; Friedman; Ormiston, 2022). Because blockchain adoption in Supply Chains is inherently interorganizational, it depends on partners aligning information-sharing practices and coordinating decisions and actions. Prior work suggests that gaps in information sharing and the resulting coordination frictions remain influential obstacles to adoption (Jovanovic *et al.*, 2022; Khan *et al.*, 2023; Liu *et al.*, 2023; Onjewu; Walton; Koliousis, 2023; Rejeb *et al.*, 2021). Yet blockchain-based initiatives in Supply Chain settings often struggle to move beyond early experimentation toward scalable deployment, not solely because of technological limitations, but because organizations and their networks frequently lack the foundational interorganizational conditions required for implementation, such as interoperability, governance arrangements, process alignment, and stakeholder collaboration (Moraes *et al.*, 2025; Najati, 2025).

This gap between technological potential and scalable implementation points to a broader readiness challenge. Organizational readiness for change refers to a shared commitment to implement change and a shared belief in collective capability (Weiner, 2009). In Supply Chain settings, readiness therefore needs to extend beyond internal preparations to include interorganizational alignment, particularly reliable information sharing and coordinated processes across partners (Liu *et al.*, 2023; Rejeb *et al.*, 2021), while addressing influential barriers such as a lack of information sharing (Khan *et al.*, 2023). Accordingly, a comprehensive readiness assessment should capture preparedness across three complementary fronts: technological foundations, organizational capabilities, and interorganizational conditions (Agi; Jha, 2022). This broader view of readiness is particularly relevant under an Industry 5.0 perspective, which goes beyond efficiency- and technology-centered transformation by emphasizing sustainability, human centricity, and resilience (European Commission, 2021). This broader readiness perspective also resonates with the growing recognition that technology adoption in interorganizational settings is not merely a technical decision (Kamble *et al.*, 2021), but an organizationally enacted and socially embedded process that unfolds over time and depends on the progressive alignment of multiple conditions.

This reality highlights the need to assess organizational readiness before making substantial investments. Readiness assessment can be understood as a systemic analysis of an organization's ability to face and undertake a transformational process or change (Pirola; Cimini; Pinto, 2020). This is particularly relevant in the case of emerging technologies, for which structured assessment based on explicit metrics and evaluation criteria is essential to support informed organizational decisions (Zamani *et al.*, 2022). Importantly, in many Supply Chain contexts, blockchain adoption is still emerging and uneven, which makes a readiness perspective more appropriate than a maturity perspective focused on post-implementation optimization.

Readiness models (RMs) help determine whether an organization is prepared to begin a development or implementation journey (Saad; Bahadori; Jafarnejad, 2021). Assessing organizational readiness is essential because firms need to understand whether they can face the challenges and opportunities associated with innovation adoption (Aziz; Yusof, 2012). Moreover, readiness assessment can support continuous improvement by clarifying capability gaps and enabling benchmarking over time (Pirola; Cimini; Pinto, 2020).

Despite growing interest in blockchain for Supply Chain applications, the literature still offers limited readiness assessment tools that simultaneously combine three essentials: solid theoretical grounding, clearly described and observable response descriptors, and an interpretable overall readiness classification that captures imbalances and non-linear interactions across technological, organizational, and interorganizational conditions. Existing readiness and maturity approaches may also face a practical usability challenge: some are so methodologically complex that they require professional judgment to interpret their results after application in enterprises (Felippes *et al.*, 2022), whereas management-oriented frameworks should remain user-friendly and avoid dependence on complex mathematical and statistical procedures for routine organizational use (Ramanathan; Samaranayake, 2022). The few studies that most closely address this need, including (Balasubramanian *et al.*, 2021), remain either contextually bounded to specific sectors such as healthcare or primarily qualitative and conceptual, rather than operationalized as standardized, organization-facing self-assessment instruments. This points to the need for a blockchain readiness model that is both methodologically grounded and practically usable in organizational settings.

Accordingly, our study develops and validates an organizational readiness assessment model for blockchain adoption in Supply Chain networks. By integrating established adoption lenses with an operational measurement structure, the model captures readiness conditions across technological, organizational, and interorganizational domains and produces an overall readiness classification suitable for pre-adoption decision-making.

To aggregate these conditions into an interpretable overall outcome, the model draws on fuzzy logic, which is particularly suited to organizational readiness assessment because it enables the treatment of intangible and subjective variables, as well as uncertain and imprecise information derived from multiple decision-makers (Bertassini *et al.*, 2022; Lotfi *et al.*, 2023). In the context of blockchain adoption in Supply Chains, readiness conditions often rely on qualitative judgments, which require appropriate modeling approaches to become actionable. Fuzzy set theory has been widely applied in Supply Chain contexts to represent subjective evaluations and handle uncertainty (Faisal; Chandra Banik; Sen Gupta, 2024; Nirmal; Nageswara Reddy; Singh, 2024). In particular, fuzzy inference systems (FIS) enable human-like reasoning through linguistic if–then rules, aggregating diverse criteria and deriving an interpretable overall readiness classification that captures non-linear interactions across conditions (Bertassini *et al.*, 2022; Zanon *et al.*, 2025).

Our study advances readiness research in four ways. First, it consolidates and validates a theory-grounded set of readiness requirements for blockchain adoption in Supply Chain networks, organized under the TOE framework. Second, it operationalizes these requirements into a replicable assessment artifact designed for organizational self-diagnosis. Third, it offers an interpretable approach for aggregating multidimensional readiness into an overall readiness outcome, supporting evidence-informed adoption decisions. Fourth, it positions pre-adoption readiness as a theoretically meaningful and empirically assessable stage in the technology adoption trajectory, highlighting that readiness in networked Supply Chain settings is an inherently interorganizational and socioorganizationally embedded condition. Methodologically, this study follows a DSR approach, iteratively designing and evaluating the proposed artifact through expert feedback and a pilot application (Hevner *et al.*, 2004; Peffers *et al.*, 2007). Guided by a DSR approach, this study addresses the following research question and sub-questions:

RQ_8. How can a readiness assessment artifact be designed, developed, and evaluated to support organizations in assessing readiness for blockchain adoption in Supply Chain networks?

To answer this RQ, we examine:

(a) which core readiness conditions should be assessed;
(b) how these conditions can be operationalized and synthesized into an interpretable overall readiness outcome; and
(c) how iterative expert evaluation and a pilot application can refine the artifact and strengthen its practical utility.

The remainder of the paper is organized as follows: Section 7.2 reviews the theoretical background and related readiness models; Section 7.3 describes the research design and methods; Section 7.4 presents the proposed readiness model and validation outcomes; Section 7.5 discusses implications, limitations, and future research; and Section 7.6 concludes the study.

7.2 Background & Related Work

This section presents the conceptual and methodological background supporting the development of the proposed readiness model. It discusses readiness as a pre-adoption assessment construct, the theoretical lenses used to structure readiness conditions, and existing approaches to blockchain readiness assessment. In addition, it introduces fuzzy set theory and fuzzy inference systems as the analytical foundation for modeling and aggregating readiness conditions.

7.2.1 Organizational readiness as a pre-adoption assessment

Readiness refers to an organization's preparedness to move forward with an upcoming initiative and is typically assessed before later stages of development or maturity are reached (Pacchini *et al.*, 2019; Wagire *et al.*, 2021). In studies of digital transformation, readiness is widely regarded as an important precondition for successful implementation, as it helps clarify whether the necessary conditions are in place before major adoption efforts begin (Khin; Kee, 2022).

Although readiness and maturity are sometimes used interchangeably, they address different practical questions. Readiness is primarily a pre-adoption assessment concerned with whether an organization is prepared to begin an implementation journey, whereas maturity is typically used after practices are in place to evaluate how advanced they have become and to support continuous improvement over time (De Carolis *et al.*, 2025; Mittal *et al.*, 2018; Röglinger; Pöppelbuß; Becker, 2012). Accordingly, this study adopts a readiness perspective to support pre-adoption decision-making for blockchain initiatives in Supply Chain contexts.

7.2.2 Structuring readiness conditions: TOE and ORC

To provide theoretical grounding for the readiness model, this study draws on two complementary lenses: the Technology–Organization–Environment (TOE) framework and Organizational Readiness for Change (ORC). TOE structures adoption conditions into three contexts: technological, organizational, and environmental. The technological context concerns relevant technologies available to or already used by the firm; the organizational context captures internal characteristics and resources that shape adoption; and the environmental context refers to external conditions such as market pressures, partner relationships, and regulation (DePietro; Wiarda; Fleischer, 1990; Tornatzky; Fleischer; Chakrabarti, 1990).

TOE has been widely used to study blockchain adoption in operations and Supply Chain settings. Prior studies have employed it to classify adoption barriers, structure adoption-related constructs, and examine the effects of technological, organizational, and environmental factors on blockchain adoption decisions (Chittipaka; Kumar; Sivarajah, 2023; Kouhizadeh; Saberi; Sarkis, 2021; Wong *et al.*, 2020a). Zhang *et al.* (2024) use the TOE framework to classify blockchain adoption factors into technological, organizational, and environmental dimensions. In the present study, TOE provides the main structure for organizing the readiness conditions to be assessed.

TOE is complemented by ORC, which captures the organizational “human side” of change. In Weiner (2009) formulation, ORC reflects a shared psychological state in which organizational members are both committed to implementing change and confident in their collective ability to do so. This perspective is particularly relevant in blockchain adoption, where implementation often depends on coordinated changes across roles, workflows, and decision routines. Taken together, TOE and ORC provide a coherent foundation for structuring blockchain readiness as both a contextual and organizationally enacted pre-adoption condition.

7.2.3 Blockchain readiness: assessment challenge and existing approaches

A central challenge in blockchain adoption is that organizations often lack a clear basis for assessing whether they are sufficiently prepared to undertake the change. Without such visibility, firms may launch initiatives prematurely, face avoidable implementation frictions, and struggle to move beyond exploratory stages. In design-oriented research, the development of a new artifact requires demonstrating that existing solutions do not yet address the problem adequately (Becker; Knackstedt; Pöppelbuß, 2009; Hevner *et al.*, 2004; Simon, 1996). Table 7.1 therefore summarizes and compares existing blockchain readiness approaches.

Table 7.1 - Overview of blockchain readiness assessment approaches

Study	Artifact	Elements	Operational details	Identified limitation
Irannezhad e al. (2021)	Readiness assessment and management approach	• Dimensions – 8 functional áreas • Items – 38 activities • Levels – Five “readiness states”	Causal mapping (FCM) + weighting (FBWM) + inference + scenario analysis*	High methodological complexity and not easy to adopt for firms.
Balasubramanian *et al.* (2021).	Readiness assessment framework	• Dimensions – 4 readiness dimensions • Items – Partial (Conceptual factors, not operationalized into explicit items) • Levels – Low/Moderate/High (categorization)	SLR + case study + thematic/axial coding + readiness level categorization	Conceptual framework; no standardized, organization-level assessment instrument.

Source: Author’s own work.
*FCM = Fuzzy Cognitive Maps (causal mapping); FBWM = Fuzzy Best–Worst Method (weight elicitation)

Among the studies reviewed, Irannezhad *et al.* (2021) and Balasubramanian *et al.*, (2021) are the closest to the organizational readiness perspective adopted here. Irannezhad *et al.* (2021) propose an analytically robust FCM-FBWM-based approach to assess blockchain readiness in Supply Chains, but its application depends on expert-driven elicitation, causal mapping, and pairwise weighting procedures, which may limit direct use by firms without methodological support. Balasubramanian *et al.* (2021), in turn, develop a blockchain readiness framework from a multi-stakeholder perspective, but operationalize it primarily through qualitative case-based assessment rather than as a standardized organization-level self-assessment instrument.

Other studies address adjacent issues rather than organizational readiness diagnosis itself. For example, Dwivedi *et al.* (2023) focus on the prioritization of blockchain readiness challenges, while Behl *et al.* (2024) examines individual-level antecedents of blockchain use. Although valuable, such approaches do not provide a repeatable organization-facing instrument for structured readiness diagnosis.

Taken together, the literature indicates that blockchain readiness approaches remain scarce and that the few studies closest to organizational assessment either require analytically demanding procedures or remain largely conceptual and qualitative. The present study addresses this gap by proposing an operationalized organization-facing readiness model that combines a standardized self-assessment questionnaire with a fuzzy inference mechanism for overall readiness classification.

7.2.4 Fuzzy Set Theory and Fuzzy Inference System

Readiness for blockchain adoption is typically expressed as a matter of degree rather than as a binary state (Lassnig *et al.*, 2022). In organizational settings, the underlying evidence is often incomplete and uneven across dimensions, and the boundaries between categories such as low and high readiness are not naturally sharp, as readiness measurement is commonly affected by ambiguity and vagueness in transitional stages (Gomes; Basilio, 2024). Fuzzy set theory (FST) was introduced precisely to represent such unsharp categories through graded membership, allowing concepts to be modeled without relying on rigid cutoffs (Zadeh, 1965).

FST has been widely used in decision-making models (Kahraman; Onar; Oztaysi, 2015). In FST, linguistic variables are represented using qualitative linguistic terms, which are defined by associating each term with a fuzzy set within a domain of discourse, distinguished by a membership/compatibility function (Zadeh, 1975). Triangular and trapezoidal membership functions are commonly employed to illustrate fuzzy numbers, primarily due to their straightforward (piecewise-linear) characteristics, and in numerous practical scenarios, they are adequate and effective for representing imprecision

(Kreinovich; Kosheleva; Shahbazova, 2020). The membership functions used in this research are detailed in Appendix B.

The fuzzy decision-making literature encompasses multiple techniques, and the choice among them should be guided by the characteristics of the problem and the objective of the assessment (Lotfi *et al.*, 2023). In this study, we use a FIS to support the final readiness classification step (Bertassini *et al.*, 2022).

FIS are rule-based models and constitute one of the most widely used applications of fuzzy logic. They perform nonlinear mappings between inputs and outputs using fuzzy sets and IF–THEN rules, thereby supporting tasks such as classification and decision support (Guillaume, 2001). In practice, an FIS follows a structured workflow in which crisp inputs are transformed into degrees of membership (fuzzification), rules are evaluated and aggregated through an inference mechanism, and the resulting fuzzy output is converted into a crisp value or category via defuzzification (Bertassini *et al.*, 2022; Gomes; Basilio, 2024).

In this study, Mamdani's inference mechanism (Mamdani; Assilian, 1975) is adopted due to its high interpretability, as it relies on linguistic rules defined by experts and enables reasoning that closely resembles human decision-making, and has been widely applied in practical contexts (Zanon *et al.*, 2025). A Mamdani-type fuzzy system is structured around four main components: fuzzification, an inference engine, a knowledge base, and defuzzification (Kacimi *et al.*, 2020). In this context, its operation relies on the interaction between the inference engine and the knowledge base, which encodes domain expertise through membership functions and fuzzy IF–THEN rules (Pourjavad; Mayorga, 2019).

Consider a fuzzy inference system in which $U = U_1 \times U_2 \times \cdots \times U_n \subset \mathbb{R}^n$ defines the input space and $V \subset \mathbb{R}$ defines the output space. The rule base comprises a set of fuzzy IF–THEN rules that establish a mapping from inputs to outputs. A typical rule $R^{(l)}$, for $l = 1, \ldots, M$, is expressed as: "IF x_1 is F_1^l AND … AND x_n is F_n^l, THEN y is G^l", where F_i^l and G^l denote fuzzy sets associated with the linguistic terms of the input and output variables, respectively (Pourjavad; Mayorga, 2019).

Within this framework, the inference process evaluates the rule base to determine the contribution of each rule to the output. In particular, the logical conjunction "AND" in the antecedent is modeled through a t-norm operator, typically the minimum due to its computational efficiency, which combines the membership degrees of the input variables

(Zanon *et al.*, 2020). Accordingly, the activation level of rule j, denoted by μ_{Ant}^{j}, is computed as defined in Eq. (1):

$$\mu_{\text{Ant}}^{j} = \min\left(\mu_{\tilde{A}_1}(\hat{x}_1), \mu_{\tilde{A}_2}(\hat{x}_2), \dots, \mu_{\tilde{A}_n}(\hat{x}_n)\right), \qquad (1)$$

where $\mu_{\text{Ant}}^{j} \in [0,1]$ represents the degree of compatibility between the input vector and the antecedent of rule j, and $\mu_{\tilde{A}_i}(\hat{x}_i)$ denotes the membership degree of the input value $\hat{x}_i$ to the corresponding fuzzy set. As defined in Eq. (1), the activation level is governed by the least satisfied antecedent condition. Subsequently, the implication step determines the contribution of each rule by combining its activation level with the corresponding consequent. In the Mamdani approach, this step is implemented using the minimum operator, as defined in Eq. (2) (Zanon *et al.*, 2025):

$$\mu^{j}(y) = \min\left(\mu_{\text{Ant}}^{j}, \mu_{\tilde{G}^{j}}(y)\right), \qquad (2)$$

where $\mu_{\tilde{G}^{j}}(y)$ denotes the membership function of the consequent fuzzy set associated with rule j. As defined in Eq. (2), this operation adjusts the consequent according to the activation level of the rule, ensuring that its contribution to the output is properly weighted. Next, the outputs of all activated rules are aggregated into a single fuzzy set. This aggregation is performed using the maximum operator, as defined in Eq. (3) (Pourjavad; Mayorga, 2019):

$$\text{AG}(y) = \max(\mu^{1}(y), \mu^{2}(y), \dots, \mu^{M}(y)), \qquad (3)$$

where M denotes the total number of rules in the rule base. As defined in Eq. (3), this step combines the individual rule outputs by selecting the highest membership degree for each value of y. Finally, the aggregated fuzzy set is transformed into a crisp value through a defuzzification process. In this study, the center of area (CoA) method is employed, as defined in Eq. (4) (Bertassini *et al.*, 2022):

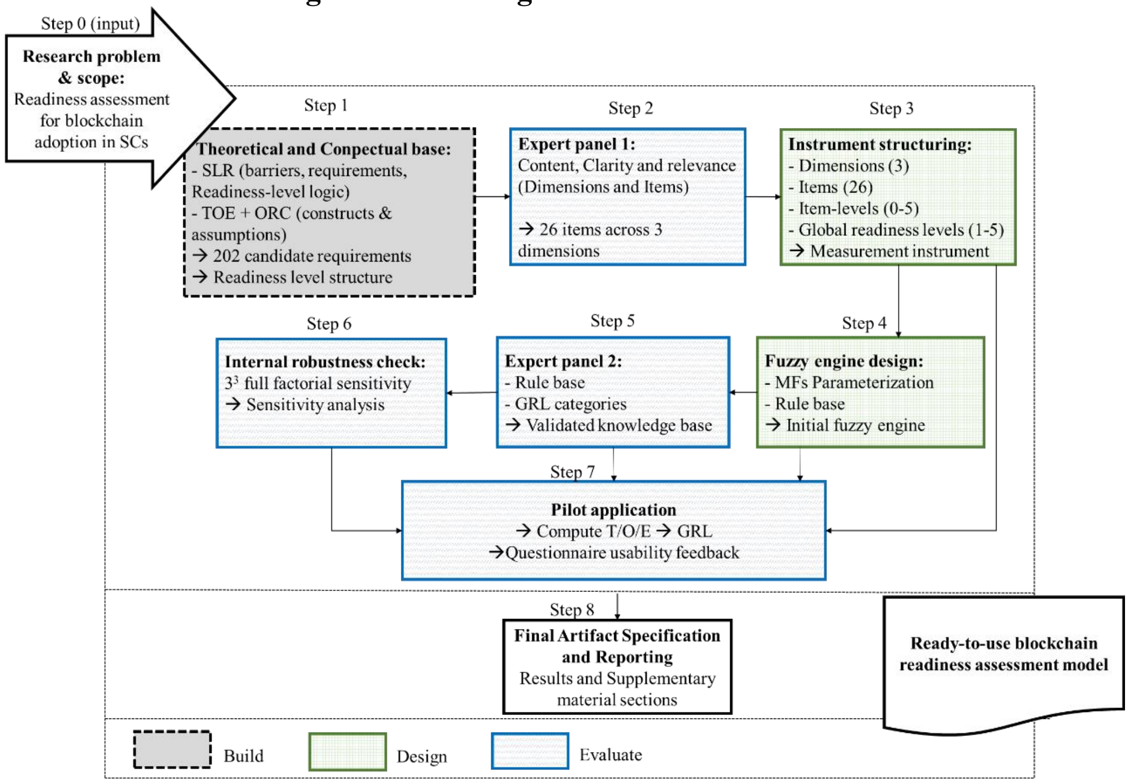
$$\bar{y} = \frac{\int y \cdot \text{AG}(y)\, dy}{\int \text{AG}(y)\, dy}, \qquad (4)$$

where $\bar{y}$ represents the final output of the FIS. As defined in Eq. (4), this method computes a representative value of the aggregated fuzzy set, thereby yielding a single scalar output.

7.3 Research design and methods

This study follows a DSR approach to develop and evaluate an organizational readiness model for blockchain adoption by firms operating in Supply Chain environments. Within a DSR approach, the study was organized into three macro-phases: necessity assessment, model development, and readiness tool evaluation. These phases were executed through iterative build–evaluate cycles, resulting in a validated readiness instrument and a fuzzy inference engine for global readiness classification. Figure 7.1 summarizes the resulting DSR-guided process and the instantiation steps reported in this paper.

Figure 7.1 - DSR-guided method overview



Source: Author's own work.

Consistent with recent readiness and maturity assessment studies in Industry 5.0 and emerging-technology contexts, this study adopts a validation strategy that combines expert-based assessment with a pilot application. Prior studies show that exploratory model and instrument development typically rely on relatively small but highly qualified purposive panels, often complemented by a pilot when the aim is to demonstrate practical applicability. For example, Ansari and Barati (2025) validated their instrument with 7 senior organizational experts through a Delphi process and subsequently applied it in a real company. By contrast, Cuevas-lopez-de-baro, Mira-solves and Verdú-jover (2025) relied on 12 multidisciplinary experts for qualitative refinement of model dimensions and statements, without pilot testing, while Samaranayake, Ramanathan and Weerabahu (2024) used six senior managers to validate the model structure, also without a pilot application. Against this backdrop, the two panels adopted in the present study (10 experts for item and dimension refinement and 12 experts for evaluating the fuzzy inference engine and global readiness levels) fall within the range observed in comparable studies, while the inclusion of a single pilot case further strengthens evidence of applicability and supports iterative refinements of the artifact.

7.3.1 Item generation and refinement (Steps 1 and 2)

An initial repository of readiness requirements was compiled from three complementary sources: (i) the 47 barriers identified in the Systematic Literature Review (SLR), reframed into positive readiness requirements; (ii) constructs derived from the TOE framework (DePietro; Wiarda; Fleischer, 1990; Tornatzky; Fleischer; Chakrabarti, 1990) and ORC (Weiner, 2009); and (iii) a focused review of readiness models for emerging technologies. This process resulted in an initial pool of 202 candidate requirements (Step 1).

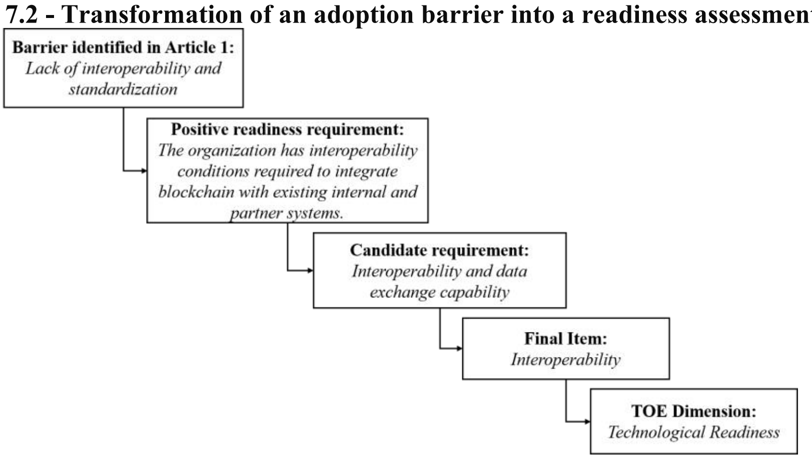
The pool then underwent internal refinement to improve parsimony and clarity. Semantically overlapping requirements were merged, redundancies were removed, and wording was standardized to ensure unambiguous interpretation in an organizational self-assessment context. This step reduced the list from 202 to 30 requirements, which were provisionally grouped into the technological, organizational, and environmental dimensions of the TOE framework.

External refinement (Step 2) was subsequently conducted through an expert panel (n = 10) with demonstrated experience in blockchain initiatives in Supply Chain contexts. Experts assessed the relevance of each requirement for blockchain adoption readiness and the appropriateness of its TOE allocation. Data were collected through one-on-one semi-structured interviews, during which experts indicated agreement or disagreement and provided suggestions for rewording, merging, removal, reassignment, or addition of items. Responses were documented in a structured spreadsheet to support systematic consolidation.

A pragmatic decision protocol was used to translate expert feedback into revisions. Items receiving disagreement from three or more experts were flagged for discussion by the research team, who made final decisions based on convergence of rationales and conceptual overlap. This process resulted in a final set of 26 readiness requirements organized into the TOE dimensions.

Figure 7.2 exemplifies how traceability was preserved from the barriers identified in the previous studies to the final readiness instrument. The barrier "lack of interoperability and standardization" was reframed as a positive readiness requirement, refined into a candidate requirement, operationalized as the final item "Interoperability," and allocated to the Technological Readiness dimension of the TOE framework.

Figure 7.2 - Transformation of an adoption barrier into a readiness assessment item



Source: Author's own work.

Table 7.2 summarizes the expert panel profile, and the final questionnaire is reported in Appendix C.

Table 7.2 - Experts (items and dimensions validation)

Expert code	Educational qualification	Position	Experience with blockchain technology	Experience with SC	Practitioner	Academic
E1	PhD - Mechanical Engineering	Senior manager Supply Chain and Logistics	8 years	25 years	✓	✓
E2	PhD - Industrial Engineering	Senior consultant - Supply Chain	6 years	12 years	✓	✓
E3	Master's degree - Industrial Engineering	Head of logistics planning	7 years	11 years	✓	✓

E4	Computer Science degree	Full Stack Developer Senior	6 years	8 years	✓	
E5	MBA - Project Management	Digital Solutions Architect	8 years	15 years	✓	
E6	PhD - Industrial Engineering	Professor/Researcher in Operations and Supply Chain Management	7 years	20 years		✓
E7	PhD - Industrial Engineering	Professor/Researcher in Operations Management	5 years	9 years		✓
E8	PhD - Industrial Engineering	Professor/Researcher in Operations Management and Blockchain Technology	7 years	10 years		✓
E9	PhD - Industrial Engineering	Professor/Researcher in Operations Management/Industry 4.0	7 years	20 years	✓	✓
E10	PhD - Industrial Engineering	Professor/Researcher in Operations and Supply Chain Management	7 years	20 years	✓	✓

Source: Author’s own work.

7.3.2 Development of readiness levels (Steps 1 and 3)

This section describes the development of readiness levels used in the proposed assessment model. It details the definition of item-level readiness scales and the construction of global readiness levels, explaining how these elements were designed to support consistent evaluation and synthesis of readiness across dimensions. The section also clarifies how these levels are integrated into the overall assessment logic of the artifact, enabling the transition from detailed evaluation to an interpretable readiness outcome.

7.3.2.1 Item-readiness levels

To operationalize item-level readiness, the study adopted a staged 0–5 rating scale inspired by capability progression logics commonly used in maturity models, particularly CMMI (Chrissis; Konrad; Shrum, 2003). Because the present study focuses on pre-adoption readiness rather than post-implementation maturity, the scale was adapted to capture the absence of initiatives at Level 0 and increasing degrees of preparation up to blockchain-readiness at Level 5.

Item-specific descriptors were then developed for each of the 26 requirements following consistent writing rules, including clarity, observability, monotonic progression, and alignment with the pre-adoption context. These descriptors were later reviewed during the pilot application to assess interpretability and usability under near-real application conditions. Table 7.6 summarizes the six levels, and the full questionnaire is provided in Appendix C.

7.3.2.2 Global readiness levels

To synthesize the organization's readiness into a single, interpretable outcome, this study defines five global readiness levels (GRL): Very Low, Low, Medium, High, and Very High. Following Monshizadeh *et al.* (2023), these linguistic levels provide an intuitive representation of readiness intensity and enable a parsimonious yet informative classification, capturing intermediate states without introducing unnecessary complexity. Importantly, these global readiness levels refer to the organization's overall readiness classification and are conceptually distinct from the item-level readiness anchors (0–5) used to assess specific capabilities within each TOE dimension.

To preserve coherence between detailed assessment and overall classification, explicit correspondence was established between item-level stages and GRL categories. Stages 0–1 were mapped to Very Low, stage 2 to Low, stage 3 to Medium, stage 4 to High, and stage 5 to Very High. The GRL were subsequently subjected to expert-based formative validation, and the readiness engine was further examined through sensitivity analysis.

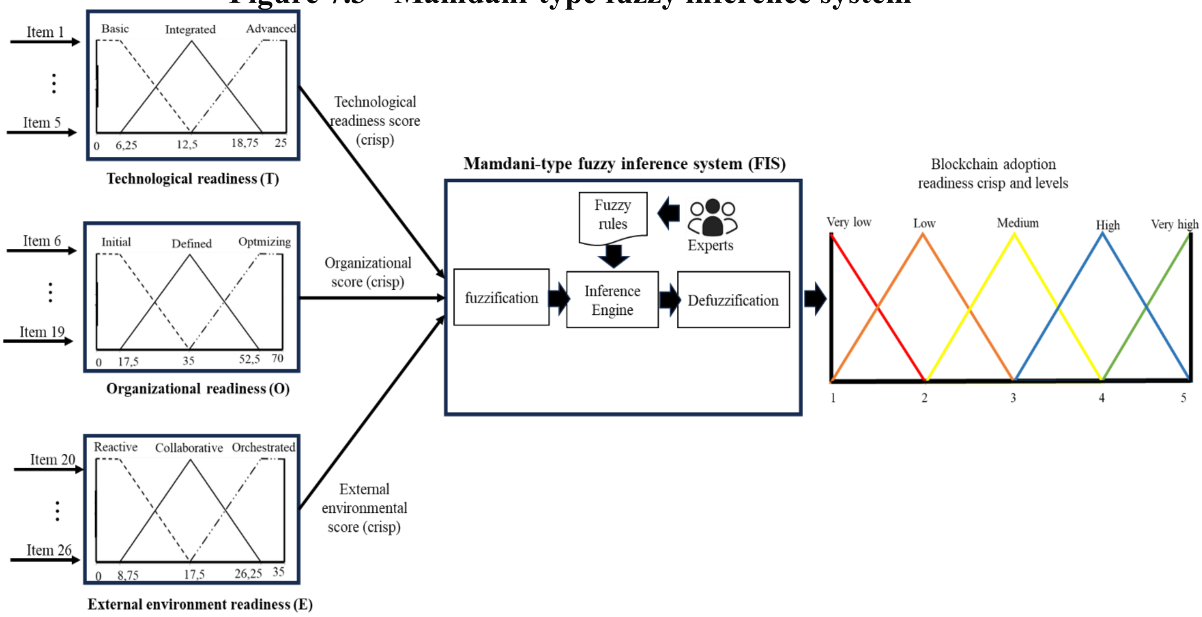
Although readiness is inherently multidimensional, the use of an overall readiness outcome is consistent with prior readiness and maturity assessment studies that seek to position the organization in relation to its current state and to support improvement planning. Monshizadeh *et al.* (2023), for example, explicitly argue that previous readiness models often neglected the effects of dimensions and concepts on overall readiness, and they model overall readiness as a meaningful assessment outcome. Likewise, De Carolis *et al.* (2025) combine an overall company maturity result with a breakdown by areas, while Ramanathan and Samaranayake (2022) use an overall readiness score to classify the focal company and support the identification of priorities and interdependencies. In the present study, the overall readiness classification serves a similar decision-support purpose, but without replacing the underlying dimensional diagnosis.

The item-level and global readiness levels were initially derived from the literature in Step 1. In Step 3, these proposed levels were integrated with the validated dimensions and items, thereby forming the visible assessment structure of the artifact. As shown in Figure 7.1, this stage corresponds to the structuring of the readiness instrument, whereas the fuzzy engine for overall readiness classification was developed subsequently as the underlying analytical component.

7.3.3 Design of the readiness assessment engine: global levels and fuzzy inference (Step 4)

Figure 7.3 summarizes the fuzzy readiness engine in a simplified form. Its general structure is consistent with the broad input–fuzzification–inference–output logic commonly found in fuzzy-based Supply Chain assessment models (e.g., Cesar; Carpinetti; Devo, 2011).

Figure 7.3 - Mamdani-type fuzzy inference system



Source: Author's own work.

7.3.3.1 Linguistic variables and membership-function parameterization

A Mamdani-type fuzzy inference system (FIS) was designed to derive an overall blockchain readiness classification from the assessment results. The system includes three inputs corresponding to the TOE dimensions and one output representing global readiness. Each input is obtained by summing item scores within its respective dimension. To preserve interpretability while keeping the rule base parsimonious, each TOE input was modeled with three linguistic terms:

a) **Technological readiness (T):** Basic, Integrated, Advanced (terminology inspired by staged readiness logic used in the IMPULS Industry 4.0 Readiness levels and descriptors (Lichtblau *et al.*, 2015);
b) **Organizational readiness (O):** Initial, Defined, Optimizing (aligned with staged maturity naming used in CMMI maturity levels (Chrissis; Konrad; Shrum, 2003);
c) **External environment readiness (E):** Reactive, Collaborative, Orchestrated (aligned with Supply Chain maturity language that explicitly contrasts reactive vs orchestrated Supply Chains and with SCOR's orchestration emphasis (Supply Chain Council, 2012).

Because each dimension score is the sum of item scores (0–5), the universes of discourse were set to the corresponding maximum totals determined by the number of items in each TOE dimension (T: 0–25; O: 0–70; E: 0–35).

Table 7.3 reports the trapezoidal and triangular fuzzy numbers used to represent the input terms.

Table 7.3 - Trapezoidal and triangular fuzzy numbers

Antecedent variable Dimensions	Linguistic term		
Technological	**Basic**	**Integrated**	**Advanced**
	(0, 0, 6,25, 12,5)	(6,25, 12,5, 18,75)	(12,5, 18,75, 25, 25)
Organizational	**Initial**	**Defined**	**Optimizing**
	(0, 0, 17,5, 35)	(17,5, 35, 52,5)	(35, 52,5, 70, 70)
External Environment	**Reactive**	**Collaborative**	**Orchestrated**
	(0, 0, 8,75, 17,5)	(8,75, 17,5, 26,25)	(17,5, 26,25, 35, 35)

Source: Author's own work.

The output variable GRL is defined on [1,5] with five terms: Very Low, Low, Medium, High, and Very High, to provide an interpretable overall classification. Table 7.4 reports the triangular fuzzy numbers used to represent the five GRL output levels.

Table 7.4 - Triangular fuzzy numbers used to represent the readiness levels

Readiness levels	Triangular fuzzy numbers
Very Low	(1, 1, 2)
Low	(1, 2, 3)
Medium	(2, 3, 4)
High	(3, 4, 5)
Very High	(4, 5, 5)

Source: Author's own work.

Triangular membership functions were adopted due to their simplicity and frequent use in Mamdani-type systems aimed at interpretability. For each input d ∈ {T,O,E}, three triangular fuzzy sets were specified using a uniform overlapping partition over the dimension range, and for the output GRL ∈ [1,5], five triangular fuzzy sets were defined with evenly spaced peaks. In the pilot, we reviewed the clarity of the linguistic labels and performed a brief plausibility check of the engine's outputs. Minor refinements, when needed, were based on recurring interpretability issues and are reported in the Results section.

The resulting dimension scores are treated as crisp inputs and are fuzzified by the predefined membership functions to obtain degrees of membership in each linguistic term (Appendix B).

7.3.3.2 Rule base construction and validation (Steps 4 and 5)

The Mamdani rule base was implemented as a complete 3×3×3 rule grid (27 rules) because each of the three TOE inputs (T, O, E) was modeled with three linguistic terms, yielding 3×3×3 possible term combinations across inputs. Accordingly, each rule corresponds to one unique combination of input terms (e.g., T=Basic, O=Defined, E=Collaborative) and assigns a single consequent term for the global readiness output (Very Low to Very High), consistent with the standard IF–THEN structure of fuzzy rule bases. To encode domain assumptions about how readiness should be aggregated while maintaining interpretability, the 27-rule grid was populated under three constraints: (i) a technological prerequisite (low technological readiness bounds the overall level), (ii) limited compensation (a very weak dimension caps the outcome, especially when the weakness occurs in Technology), and (iii) high-readiness sufficiency (Very High is assigned only when all three dimensions are simultaneously high).

Technological readiness was treated as a prerequisite because blockchain adoption requires a minimum digital foundation, including data infrastructure, interoperability, security, privacy, and data reliability. When these conditions remain at a Basic level, organizational and external conditions cannot fully compensate for the lack of technical feasibility. Thus, technology was modeled as a necessary but not sufficient condition for blockchain adoption readiness.

The engine was specified as Mamdani-type (AND/implication via the minimum operator; aggregation via the maximum operator), with centroid (center-of-gravity) defuzzification used to obtain the final crisp GRL score. The corresponding formulations are reported in Section 7.2.4 (Eqs. 1–4).

The fuzzy inference engine was validated formatively to refine the artifact prior to the pilot application, consistent with the DSR logic in which artifacts are improved through iterative cycles of building and evaluation. For this stage, we convened a dedicated panel of 12 experts, selected according to the same eligibility criteria used for the first expert panel, focusing exclusively on assessing (i) the coherence of the rule base and (ii) the clarity and appropriateness of the linguistic output terms (global readiness levels ranging from Very Low to Very High). Table 7.5 summarizes the experts' profiles.

Table 7.5 - Experts (fuzzy inference engine validation)

Expert code	Educational qualification	Position	Experience with blockchain	Experience with SC	Practitioner	Academic
EE1	PhD - Industrial Engineering	Senior consultant - Supply Chain	6 years	12 years	✓	✓
EE2	PhD - Mechanical Engineering	Senior manager - Supply Chain and Logistics	8 years	25 years	✓	✓
EE3	PhD - Applied Computing	Product Manager - Distributed computing (blockchain)	10 years	5 years	✓	
EE4	MBA - Digital Business	Tech Manager	5 years	5 years	✓	
EE5	Master's degree - Computer Science	Innovation Manager	6 years	5 years	✓	✓
EE6	Master's degree - Industrial Engineering	Head of logistics planning	7 years	11 years	✓	✓
EE7	PhD - Industrial Engineering	Professor/Researcher in Operations and Supply Chain Management	7 years	20 years		✓
EE8	PhD - Industrial Engineering	Professor/Researcher in Operations and Supply Chain Management	7 years	20 years	✓	✓
EE9	PhD - Industrial Engineering	Professor/Researcher in Operations Management/Industry 4.0	7 years	20 years	✓	✓
EE10	PhD - Industrial Engineering	Professor/Researcher in Operations Management/Industry 4.0	5 years	7 years		✓
EE11	PhD - Industrial Engineering	Professor/Researcher in Operations Management and Blockchain Technology	7 years	10 years		✓
EE12	PhD - Industrial Engineering	Professor/Researcher in Operations Management/Industry 4.0	5 years	9 years		✓

Source: Author's own work.

The procedure comprised the presentation of: (i) the FIS architecture (three TOE-based inputs and a single global output), (ii) the linguistic terms defined for inputs and output, and (iii) the full set of 27 IF–THEN rules in the rule base. No numerical calibration was performed at this stage; experts focused on the logical and semantic adequacy of the rules and the output labels. Experts assessed whether the rule consequents were appropriate (namely, whether the proposed global readiness levels (Very Low to Very High) were coherent with each input combination) recording agreement/disagreement and providing a rationale. Revisions were implemented only when disagreement was both repeated across experts and converged toward the same alternative consequent. The expert review resulted in a small number of targeted revisions to the initial rule grid; the results are reported in Section 7.4.3.1 and Appendix D.

7.3.3.3 Internal robustness check: Sensitivity analysis (Step 6)

To complement expert validation, we conducted a full factorial sensitivity analysis to assess the internal consistency of the fuzzy readiness engine across the input space. Following established practice in FIS robustness checks, a complete 3^k design was implemented using the peak membership values for each linguistic term, and interaction plots were examined to verify monotonic behavior and plausible interaction patterns implied by the rule base. Results are reported in Section 7.4.3.2.

7.3.4 Artifact instantiation: pilot application of the instrument (Step 7)

The pilot application was conducted in a large agro-industrial cooperative based in the Center-West of Brazil (identity anonymized). The organization operates through a multi-unit structure and coordinates multiple actors across upstream, processing, and commercialization activities, including member-producers, internal business functions, and external Supply Chain partners. Its operations require recurrent recording, standardization, verification, and exchange of information across organizational and interorganizational interfaces. This context was considered particularly suitable for piloting a blockchain readiness instrument in Supply Chains because it combines internal operational complexity with recurring coordination needs across Supply Chain relationships. To preserve confidentiality, the organization is not identified and potentially revealing details are intentionally omitted.

Before the instrument was administered, a preliminary meeting was conducted with organizational representatives directly involved in planning the pilot application: the innovation manager and the administrative excellence supervisor. This meeting was used to present the study, explain the purpose and structure of the instrument, clarify the logic of dimension assignment, and align the application procedure with the organization's internal structure, decision flows, and information responsibilities.

The actual data collection then followed a criterion-based purposive sampling strategy using key informants (Homburg *et al.*, 2012) with direct responsibility and domain knowledge for each instrument dimension. The pilot was therefore structured around one primary respondent per dimension, rather than multiple respondents answering the same module. Three respondents participated in the pilot application. Specifically, the IT manager completed the Technological dimension, the innovation manager completed the Organizational module, and the Supply Chain manager completed the External Environment module. Because some items involved cross-functional knowledge, respondents were allowed to consult other internal areas when necessary. In particular, the innovation manager could consult finance, legal/compliance, HR, and IT, while the Supply Chain manager could consult commercial/sales, procurement, and IT. This domain-assigned key-informant design was intended to reduce single-informant bias and improve the fit between questionnaire content and respondents' access to organizational evidence and knowledge.

More broadly, the instrument is intended to be applied through one primary respondent per dimension, as each TOE dimension requires distinct types of organizational knowledge and evidence. Thus, the Technological module is best assigned to an IT-related manager, the Organizational module to a respondent with cross-functional and strategic visibility, and the External Environment module to a Supply Chain or partner-facing manager. Consultation with other internal areas may be used when needed, but the recommended structure remains one primary respondent per module.

Overall, the pilot instantiation combined a preliminary alignment meeting with the subsequent completion of the instrument by three dimension-assigned key informants. This procedure allowed the artifact to be examined under near-real organizational conditions while preserving role specialization in data provision and strengthening the credibility of the pilot application as an evaluation step within the DSR process.

Questionnaire structure (blockchain adoption readiness instrument):

The research instrument was implemented as three electronic questionnaires (Google Forms), corresponding to the Technological, Organizational, and External Environment (SC) dimensions. Each form begins with a brief statement of purpose and scope and explicitly indicates which items belong to that dimension: Technological (items 1–5), Organizational (items 6–19), and External Environment (items 20–26).

All three forms include an Informed Consent section describing the objectives, procedures, confidentiality, and voluntariness, followed by an option to agree to participate. The core section of each form comprises the readiness assessment items. Each item is presented with (i) a title, (ii) a short description of the aspect being assessed, and (iii) an operational question (e.g., "how is…" / "to what extent…"). Responses use an ordinal 0–5 scale anchored by readiness descriptors ranging from "Absent" to "Ready/Adaptive – blockchain-ready."

At the end of each questionnaire module, the instrument itself was evaluated using two constructs adapted from the Technology Acceptance Model (TAM) (Davis, 1989): perceived usefulness and perceived ease of use. In this study, perceived usefulness refers to the extent to which respondents considered the questionnaire useful for diagnosing blockchain adoption readiness and supporting subsequent action planning. Perceived ease of use refers to the extent to which respondents perceived the questionnaire as clear, understandable, and not overly demanding to complete. These items were included to support the evaluation of the artifact from a usability and practical applicability perspective. Therefore, they were not intended to measure respondents' intention to adopt blockchain or their acceptance of blockchain technology. Instead, they assessed whether the readiness assessment instrument was perceived as useful and easy to use in an organizational context. This distinction is important because the pilot application aimed not only to generate a readiness diagnosis, but also to observe how the instrument performed in practice and to identify opportunities for refinement.

Finally, respondent profile information was collected through broad categories, such as functional area, role level, years of experience, and tenure in the company. These data were used only for general characterization of the respondents and to contextualize the pilot application, without identifying individuals or supporting individual-level analysis.

In addition, an open-ended question was included to solicit suggestions for improvement. This question was designed to identify ambiguous points and guide instrument refinements after the pilot; the final specification and the resulting changes are reported in the Results section. The full questionnaire is provided in Appendix C, presenting the final post-pilot version incorporating refinements derived from respondents' feedback.

The final artifact specification and reporting (Step 8) are presented in the Results and Appendices C and D.

7.4 Results (Artifact specification and validation outcomes)

This section presents the model specification and validation outcomes, including the final readiness requirements, readiness levels, fuzzy inference engine, and results from expert evaluation and pilot application.

7.4.1 Requirement repository and final item set

Expert-based refinement led to substantive changes in the initial 30-item repository, resulting in a final set of 26 readiness requirements. After consolidating the panel's feedback (n=10) through an internal synthesis, we implemented four types of revisions: (i) merging partially redundant items to improve parsimony, (ii) removing requirements considered non-essential for blockchain readiness in Supply Chain contexts, (iii) adding requirements to address gaps identified by experts, and (iv) reallocating selected items to a more appropriate TOE dimension.

A representative removal was the item "decentralization." Several experts argued that decentralized decision-making is not a prerequisite for readiness because blockchain adoption decisions often follow a top-down logic within organizations. In contrast, experts highlighted missing requirements related to sustainability considerations, business model implications, and business process preparedness; these aspects were incorporated into new items. Finally, experts also recommended adjustments to TOE allocation and item wording when the conceptual fit was clearer. For example, "access to smart products," initially positioned within the organizational dimension, was integrated and re-specified within the technological dimension. Overall, these exclusions, merges, additions, and reallocations resulted in a finalized set of 26 expert-validated requirements (Appendix C).

7.4.2 Final readiness level system

This section presents the final readiness level system, describing the structure of item-level and global readiness levels and their role in supporting readiness assessment and classification.

7.4.2.1 Final item-level descriptors

The model's item-level assessment adopts a standardized six-level scale (0–5) applied consistently across all requirements. This generic scale provides a shared progression reference that reduces interpretive variability and enables comparable scoring across items (see Table 7.6). A similar staged logic has been adopted in recent digital maturity/readiness models, including 3D-CUBE (which uses a 0–5 readiness scale) and DREAMY (inspired by CMMI), illustrating the prevalence of level-based structures in digital transformation assessments (De Carolis *et al.*, 2025; Felippes *et al.*, 2022).

The descriptors (Table 7.6) were designed to capture pre-adoption readiness, not blockchain maturity. Thus, higher scores do not indicate that blockchain is already implemented or mature in use. Instead, they indicate that the organization has developed the processes, resources, governance mechanisms, knowledge, and enabling conditions that would facilitate adoption if the decision to implement blockchain were made. In this sense, Levels 3 to 5 represent increasing degrees of preparedness for adoption, rather than evidence of post-adoption performance.

Table 7.6 - Generic item-level readiness descriptors (Levels 0–5)

Item-level	Descriptors
Level 0 – Absent	There are no initiatives related to the item. The organization does not address this topic in terms of practices, assigned responsibilities, or resources (i.e., there is no action and no direction).
Level 1 – Initiated	The item is recognized as relevant, and isolated initiatives begin to emerge, but they are not yet formalized. There is no planning, no clearly assigned owner, and no established routines.
Level 2 – Managed	Basic practices exist, and the item is managed to some extent, although management remains limited and largely reactive. Resources begin to be allocated, but standardization is low and integration with other areas is minimal.

Level 3 – Defined	Processes and/or policies related to the item are formalized and documented. Responsibilities and governance are defined, and there is partial alignment with organizational goals and practices.
Level 4 – Prepared for Blockchain Integration	The item is structured to support blockchain integration: the necessary processes, resources, and enabling mechanisms are defined and ready for operation (integration conditions are planned and feasible).
Level 5 – Blockchain-Ready and Adaptive	The item is supported by a mature and adaptive capability that enables rapid scaling once a decision to adopt blockchain is made. Practices are institutionalized, resources are available, responsibilities are clear, and mechanisms are in place to adjust quickly and improve continuously as technological, regulatory, and market conditions evolve.

Source: Author's own work.

Table 7.7 provides an example of the six-level logic as applied to Item 15. This item assesses the extent to which the organization demonstrates trust in and a favorable perception of blockchain, recognizing and valuing its potential benefits and opportunities for operations.

Table 7.7 - Item-level readiness descriptors Positive perception toward blockchain

Score	**How POSITIVE IS YOUR ORGANIZATION'S PERCEPTION of blockchain technology and its potential benefits for business operations?**
0	The organization has no awareness or understanding of blockchain technology. Members do not recognize its relevance or potential benefits, and there is no discussion about its adoption.
1	The organization is aware of blockchain as an emerging technology but perceives it as distant or irrelevant to its operations. Discussions are informal, and skepticism about its applicability is common.
2	The organization acknowledges that blockchain may offer benefits and has circulated introductory information internally (e.g., articles or brief presentations). Some employees show interest, but perceptions remain mixed, and there is no structured effort to communicate advantages or opportunities.
3	The organization has a generally positive perception of blockchain. Formal communication initiatives (e.g., internal presentations, newsletters) explain their potential benefits for business processes. Employees understand its strategic relevance, and blockchain is considered in discussions about future opportunities.
4	The organization strongly believes in the benefits of blockchain and includes it in strategic planning. Members can clearly identify opportunities for its application in operations, and leadership actively promotes awareness and engagement through structured programs.
5	The organization has a deeply embedded positive perception of blockchain. Employees and leadership share a clear understanding of its value and maintain continuous initiatives to explore new applications. This mindset supports rapid adoption and adaptation when the decision to implement is made.

Source: Author's own work.

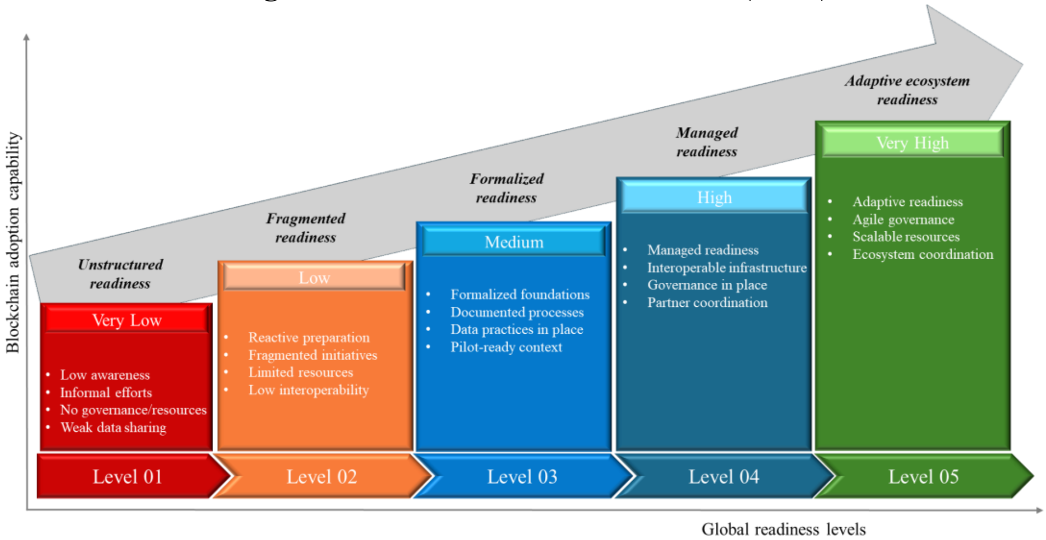
The generic scale was applied to each requirement, as exemplified in Table 7.7, resulting in item-specific descriptors. The complete questionnaire, including item-specific level descriptors for all items, is provided in Appendix C.

7.4.2.2 Final global readiness levels

The following definitions summarize the finalized GRLs (Very Low to Very High) after expert-based formative validation. They serve as the interpretive descriptor for the model's GRL outputs (Figure 7.4):

a) **Very Low:** No structured readiness is in place: governance and dedicated resources are absent, and foundational digital integration is negligible. Interorganizational collaboration and data-sharing arrangements are fragmented, limiting any realistic cross-partner traceability or shared-ledger initiative;
b) **Low:** Early preparation exists but remains reactive and unstandardized, with limited governance and resource allocation. Interorganizational engagement is incipient, and weak interoperability, identity, and cybersecurity/privacy foundations constrain progress beyond isolated exploratory efforts;
c) **Medium:** Core internal conditions are formalized and partially integrated: relevant processes/policies are documented, and basic data-management practices (e.g., standardization, integrity checks, auditability) are in place. External engagement occurs in selected, controlled contexts, indicating readiness for structured proof-of-concept;
d) **High:** The organization is prepared to initiate adoption with managed risk: interoperable infrastructure, governance/compliance mechanisms, and planned resources are in place. Partner relationships are sufficiently structured to support data standards and coordinated implementation planning;
e) **Very High:** Beyond preparedness, adaptive capability is established: governance is agile, resources are readily mobilizable, and continuous-improvement mechanisms support rapid scaling across partners. High coordination, trust, and standardization enable timely adjustment to evolve technological, regulatory, and market requirements and support advanced blockchain-enabled capabilities at scale.

Figure 7.4 - Global Readiness Levels (GRL)



Source: Author's own work.

7.4.3 Final fuzzy engine specification

Figure 7.3 summarizes the final fuzzy readiness engine. The engine takes the three TOE dimension scores (T, O, E) as inputs and produces a single Global Readiness Level (GRL) as output. The final specification retains the Mamdani-type structure defined in the design phase and a complete 27-rule base linking the three input dimensions to the five GRL categories. Full technical details of the final engine are provided in Appendix B (membership functions) and Appendix D (final fuzzy rule base).

7.4.3.1 Expert refinement of the fuzzy readiness engine

This formative validation aimed to refine the fuzzy inference engine before the pilot application by assessing (i) the logical coherence of the rule base and (ii) the clarity and appropriateness of the global readiness labels (Very Low to Very High). A panel of 12 domain experts reviewed the engine, focusing on the semantic adequacy of rule consequents rather than on numerical calibration.

Experts were presented with: (1) the FIS structure (three TOE-based inputs and one global output), (2) the linguistic terms used for each input and the output, and (3) the complete set of 27 IF–THEN rules arranged as a 3×3×3 grid. Each expert evaluated whether the consequent assigned to each input-term combination was appropriate, recording agreement/disagreement and providing a brief rationale and, when applicable, an alternative suggested output level.

The research team conducted a structured analysis of the expert feedback in three steps. First, responses were consolidated rule-by-rule to identify patterns of recurrent disagreement. Second, for rules with higher disagreement, we examined whether dissenting experts converged on the same alternative output level, as this indicates a consistent interpretive expectation rather than isolated preferences. Third, revisions were prioritized only when (a) disagreement was both repeated and consistent across multiple experts and (b) the alternative consequents suggested by experts showed convergence (i.e., different experts independently recommending the same output level for the same rule).

Overall, feedback indicated that the rule base was largely coherent with the intended aggregation logic. Most disagreements were isolated, typically involving a single expert questioning the proposed consequent for a given rule, while the remaining experts agreed with the original mapping. In contrast, consistent multi-expert disagreement (where different experts independently converged on the same alternative readiness level) occurred only for three rules. This localized convergence provided a clear basis for targeted revisions, whereas isolated disagreements were treated as individual preferences and did not trigger changes.

Based on this analysis, three rules (out of 27) were revised. The revisions consisted of adjusting the consequent readiness level for rules where expert disagreement was both recurrent and convergent toward a single alternative output. All other rules were retained as originally specified because expert feedback indicated sufficient coherence and interpretability. The revised 27-rule table, including the three changes, is reported in Appendix D.

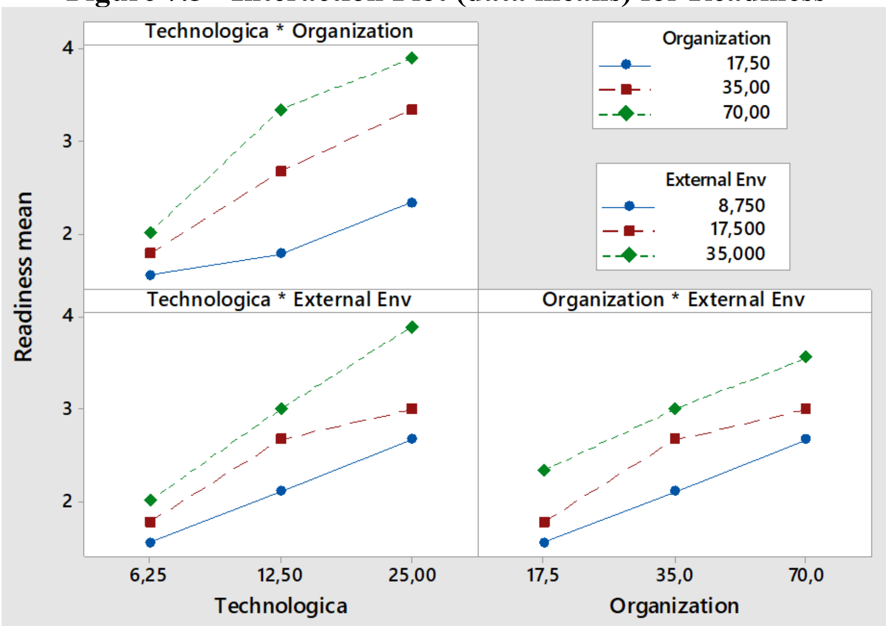
With respect to the other elements assessed in the panel, experts largely endorsed the proposed GRLs and the clarity of the linguistic output terms (Very Low to Very High). No systematic concerns or convergent recommendations emerged regarding the number of readiness levels, their ordering, or their wording. As a result, suggested changes were limited to the rule base, where only three rules received convergent alternative recommendations and were subsequently revised.

7.4.3.2 Sensitivity Analysis and Internal Consistency Check

To evaluate the sensitivity and internal consistency of the FIS developed in this study, a full factorial design approach was employed (Montgomery, 2017). This technique is commonly adopted to investigate interaction effects among input variables on the output response, as well as to assess the relative influence of each input according to the structure of the FIS rule bases (Bertassini *et al.*, 2022; Zanon *et al.*, 2025). In this context, a complete 3^k factorial design was implemented for the FIS rule bases under analysis. The input levels were defined based on the highest membership degrees associated with each linguistic term. The experimental designs and subsequent analyses were performed using Minitab 18® software.

Figure 7.5 presents the interaction plots for the three pairwise combinations of the TOE dimensions, based on the full-factorial sensitivity analysis of the fuzzy readiness engine.

Figure 7.5 - Interaction Plot (data means) for Readiness



Source: Author's own work.

The interaction plots indicate that readiness is influenced not only by the individual effects of technological, organizational, and external environment factors, but also by their combined effects. Specifically, the non-parallel patterns observed in the Technological × Organizational interaction suggest that the impact of technological capability on readiness becomes more pronounced at higher levels of organizational maturity, indicating an interaction effect between these two dimensions. Similarly, the interaction between Technological and External Environment factors reveals that favorable external conditions amplify the positive effect of technological capability, although this interaction appears to be of moderate intensity. In addition, the Organizational × External Environment interaction demonstrates that organizations with more developed governance, competences, and process adaptability are better positioned to leverage improvements in the external environment, resulting in greater increases in readiness.

These interaction effects also provide an internal consistency/robustness check for the validation of the rule base, as the observed response patterns are consistent with the logical structure embedded in the model. In particular, the monotonic increases in readiness across factor levels, combined with the presence of synergistic effects, are aligned with the underlying IF–THEN rules, in which higher readiness levels emerge from the joint presence of favorable technological, organizational, and environmental conditions. Therefore, the coherence between the interaction results and the rule-based reasoning reinforces the robustness and interpretability of the proposed model, indicating that the rule base adequately captures the underlying relationships among the input variables. This analysis complements expert validation by confirming that the engine behaves consistently across the input space, rather than only at the observed input configuration.

7.4.4 Pilot application

This section reports the outcomes of the pilot application, focusing on (i) the readiness classification produced by the fuzzy engine from the organization's questionnaire responses and (ii) respondents' evaluation of the instrument in terms of perceived usefulness and ease of use. The pilot was conducted to verify applicability in a real Supply Chain setting, identify interpretability issues, and inform minor refinements prior to broader use.

7.4.4.1 Organizational readiness assessment (engine outputs)

The pilot was conducted in a real organizational setting, with a focal organization operating within a supply chain network. Accordingly, the unit of assessment in the pilot was the focal organization, rather than the entire supply chain network as a collective unit. The External Environment dimension was included to capture network-related conditions, such as collaboration, partner relationships, digital connectivity, transparency, and compliance; however, these conditions were assessed from the focal organization's perspective and available knowledge.

Respondents completed the instrument by providing item-level scores (0–5) and, when needed, consulting relevant functions to ensure accurate responses. Item scores were aggregated into TOE dimension scores (T, O, E) and processed by the specified fuzzy inference engine to produce a GRL; pilot computations were performed in MATLAB using the Fuzzy Logic Toolbox.

Table 7.8 summarizes the TOE dimension scores obtained in the pilot application. Scores are reported on each dimension's universe of discourse, where higher values indicate higher readiness within the corresponding dimension.

Table 7.8 - Pilot dimension scores and ranges (T, O, E)

Dimension	Range	Pilot score	% of maximum
Technological (T)	0–25	**14**	56,0%
Organizational (O)	0–70	**6**	8,6%
External environment (E)	0–35	**14**	40,0%

Source: Author's own work.

Table 7.8 presents the pilot TOE scores and their normalized values. The profile indicates higher Technological readiness (14/25; 56.0%) and moderate External Environment readiness (14/35; 40.0%), while Organizational readiness is markedly lower (6/70; 8.6%), suggesting that organizational readiness is the primary constraint in this pilot readiness profile once an adoption decision is made.

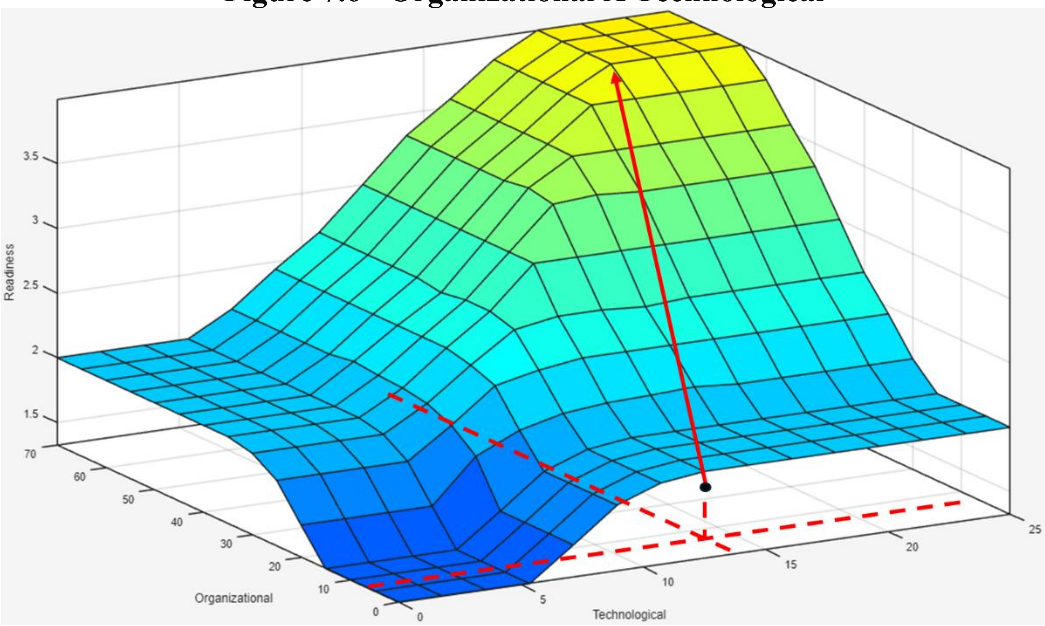
The markedly lower Organizational score suggests an organizational bottleneck in the readiness profile; however, the final GRL is determined by the fuzzy rule base, meaning that the overall classification must be interpreted in conjunction with the rule-based mapping and the activated rules.

Based on these inputs, the fuzzy engine produced a crisp GRL score of 1.92 (1–5 scale), corresponding to the Low readiness category. The organization shows some early conditions that could support blockchain exploration, but these conditions remain fragmented, weakly coordinated, and insufficiently institutionalized to support a structured adoption initiative. Severe organizational deficiencies constrain the conversion of existing technological and external-environment conditions into higher overall readiness. This value is a consolidated signal derived from the joint TOE configuration and was computed using the inference and defuzzification settings specified in Section 7.2.4.

7.4.4.2 Diagnostic insights/priority areas

The response surface plots (Figure 7.6, 7.7 and 7.8) show how the Mamdani-type FIS combines the three TOE dimensions into the GRL, while also indicating how the organization could improve its readiness from its current position. In the three plots, the black dot marks the current configuration (T = 14, O = 6, E = 14), the dashed red lines project this point onto the input axes, and the solid red arrows indicate the direction in which GRL increases more strongly.

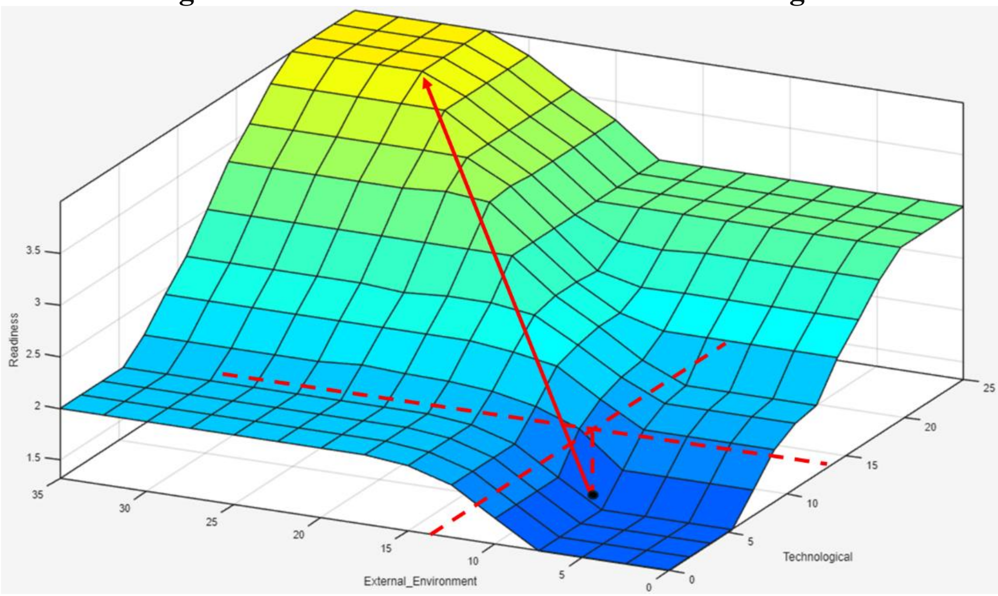
Figure 7.6 - Organizational X Technological



Source: Author’s own work.

The Organizational × Technological surface (Figure 7.6) suggests that the most immediate improvement lies in raising Organizational while preserving and moderately extending Technological. The arrow points mainly toward higher Organizational, with only a smaller movement along Technological, indicating that additional technological capability alone would not be the most effective route to increase GRL. Instead, the model suggests that the organization should first move out of the low-Organizational region by strengthening governance, top management support, internal competence, and the adaptability of its policies, processes, and business models for blockchain adoption. This would allow the existing technological base to generate greater readiness gains, as transformational leadership has been shown to strengthen organizational agility, while both positively influence digital transformation (AlNuaimi *et al.*, 2022).

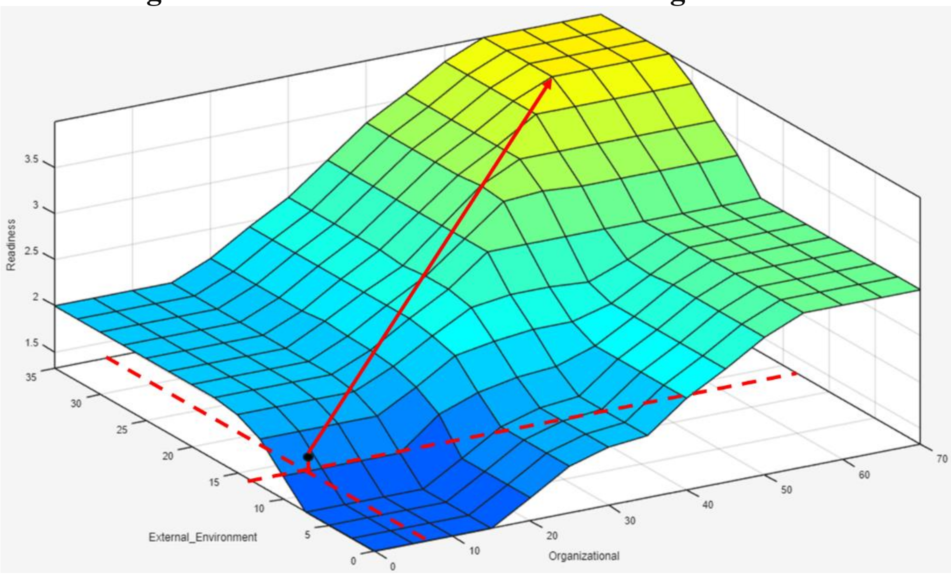
Figure 7.7 - External Environment X Technological



Source: Author's own work.

The External Environment × Technological surface (Figure 7.7) indicates a complementary path. Here, the arrow follows a more diagonal direction, pointing toward simultaneous increases in External Environment and Technological. This suggests that, once the internal bottleneck is reduced, the organization can improve readiness more effectively by aligning its technological base with external Supply Chain conditions. In practical terms, this means prioritizing improvements in data reliability, interoperability, and communication infrastructure on the technological side, while, on the Supply Chain side, advancing digital connectivity, transparency among actors, and more structured information exchange with suppliers and customers. The plot suggests that coordinated improvements in Technological and External Environment are more advantageous than progress in either dimension in isolation.

Figure 7.8 - External Environment X Organizational



Source: Author's own work.

The External Environment × Organizational surface (Figure 7.8) reinforces the central role of Organizational, while also showing that gains in E are more effective when accompanied by internal organizational development. The arrow points diagonally upward, indicating that readiness rises more strongly when Organizational and External Environment improve together. At the current configuration, however, Organizational appears to be the stronger local driver, with E acting as a reinforcing dimension. In practical terms, this suggests that external collaboration is unlikely to compensate for weak internal structure; rather, improvements in interorganizational conditions are likely to yield stronger readiness gains when the organization simultaneously strengthens its governance, resources, competences, and internal adaptability. Behnke and Janssen (2020) similarly argue that Supply Chain systems must first be modified and organizational measures taken before blockchain can be used successfully.

Taken together, the three arrows suggest a locally prioritized but still synergistic improvement path. The first priority is to strengthen Organizational, because the organization is currently located in a very low-Organizational region and this dimension is the main upward direction in two of the three response surfaces (O × T and E × O). In the current configuration, weak Organizational constrains the gains that could otherwise be obtained from Technological and External environment. Strengthening Organizational therefore helps the organization move out of this constrained region and creates the conditions for existing technological capabilities and future external-environment improvements to translate into stronger increases in GRL. From this point, readiness can be improved further by leveraging the existing T base more effectively and by reinforcing E in combination with the now stronger Organizational and Technological, so that the three dimensions can interact more productively.

This reflects the logic embedded in the rule base: readiness grows through interaction across dimensions, but compensation is bounded, meaning that strength in one dimension cannot fully offset severe weakness in another. The arrows make this visible by showing that the route to higher readiness is not movement along a single axis, but coordinated progression toward a more balanced TOE configuration. This is consistent with the view that blockchain adoption in Supply Chains depends on the interaction of technological, organizational, and external Supply Chain conditions, such that strength in technology alone does not ensure adoption in the absence of internal alignment and interorganizational support (Agi; Jha, 2022; Chittipaka; Kumar; Sivarajah, 2023; Kouhizadeh; Saberi; Sarkis, 2021).

7.4.4.3 Instrument evaluation (usefulness & ease of use)

After completing each module, respondents rated two instrument-evaluation items capturing perceived usefulness (i.e., whether the questionnaire helps diagnose readiness and support action planning) and perceived ease of use (i.e., clarity and the perceived effort required to complete the questionnaire). Overall, the feedback indicated good acceptability and a broadly positive view of usefulness across the three dimensions. The External Environment module was rated as “partially agree” for perceived usefulness and “totally agree” for perceived ease of use; the Organizational module was rated as “agree” for perceived usefulness but “partially disagree” for perceived ease of use; and the Technological module was rated as “partially agree” for both perceived usefulness and perceived ease of use.

To better understand these ratings, we held brief informal follow-up conversations with the same respondents to clarify what made some items easier or harder to answer. Respondents consistently emphasized the need to make response descriptors more objective and concise, particularly at higher readiness levels (3–5); this need was most salient in the Organizational module, where longer descriptions increased the effort required to compare options. They also suggested rephrasing highly technical terms in language more familiar to the organizational context to reduce variation in interpretation across functions. In addition, they suggested minor terminological adjustments to better align with cooperative settings (e.g., recognizing that "suppliers" may include member-producers in agricultural cooperatives). Importantly, these evaluation items were used to assess the questionnaire itself (its perceived utility and usability), not respondents' acceptance of blockchain technology. Moreover, because the instrument is designed to be generic for organizations operating in Supply Chain contexts, it is not tailored to a single company; therefore, limited wording adaptations may be necessary to align with the terminology and roles of each specific setting without changing the underlying constructs being assessed.

7.5 Discussion

This section discusses the implications of the proposed readiness model, highlighting its main contributions, theoretical alignment, and practical relevance for supporting blockchain adoption decisions.

7.5.1 Key findings and what the model reveals

Our study delivers a formatively validated readiness artifact that operationalizes blockchain adoption readiness in Supply Chain contexts through a structured, multidimensional, and decision-oriented assessment. The artifact integrates a TOE-based instrument with 26 readiness requirements distributed across the technological, organizational, and external-environment dimensions, together with standardized 0–5 item-level descriptors that support consistent and comparable diagnosis across requirements.

The model then synthesizes the three TOE dimensions into a global readiness result through an explicit and interpretable fuzzy rule base, while preserving the diagnostic value of dimension-level assessment. In this way, the artifact reveals not only the organization's overall readiness position, but also where the main constraints to progress are located, making visible the multidimensional and non-compensatory nature of blockchain adoption readiness in Supply Chain settings.

The pilot application provides an illustrative instance of what such a readiness profile can reveal about the current state of blockchain adoption preparedness in Supply Chain contexts. The participating organization exhibited a markedly asymmetric profile:

moderate technological and external-environment readiness coexisted with severely underdeveloped organizational conditions, producing a Low global readiness classification. This pattern is consistent with broader evidence suggesting that blockchain initiatives in Supply Chains frequently stall not because of technological immaturity, but because the organizational and interorganizational foundations required for scalable deployment remain insufficiently developed (Moraes *et al.*, 2025; Najati, 2025). Rather than pointing to a single corrective action, the readiness profile exposes a sequenced improvement path: organizational capabilities must first be strengthened before gains in technological and external-environment conditions can translate into meaningful advances in overall readiness. This finding illustrates how the model can support more deliberate and realistic planning of blockchain adoption trajectories, moving organizations from fragmented experimentation toward structured pre-adoption development.

7.5.2 Theoretical contributions

First, our study contributes to the emerging-technology readiness literature by reconceptualizing readiness as a structured pre-adoption condition rather than a broad and loosely specified set of antecedents and enabling factors. Prior research has already framed readiness as a multidimensional and pre-adoption phenomenon distinct from post-adoption maturity (Lokuge *et al.*, 2019; Pacchini *et al.*, 2019; Pirola; Cimini; Pinto, 2020; Tripathi; Gupta, 2021). At the same time, the literature has pointed to substantial heterogeneity in how readiness models are structured and evaluated, limiting conceptual consistency and cumulative knowledge building (Hizam-hanafiah; Soomro; Abdullah, 2024; Unlu; Demirors, 2023). Against this backdrop, the present study advances theory by specifying blockchain readiness as an assessable construct with an explicit evaluative logic, thereby strengthening its conceptual clarity and analytical usefulness in pre-adoption research.

Second, the study extends blockchain adoption research in Supply Chains by theoretically repositioning TOE from an explanatory adoption lens to the design backbone of a RM. TOE has been widely employed to explain technology adoption across organizational contexts and has also been used to frame blockchain-related adoption factors (DePietro; Wiarda; Fleischer, 1990; Tornatzky; Fleischer; Chakrabarti, 1990). However, the present study goes beyond using TOE as a classification device for adoption determinants and instead repurposes it to structure the conceptualization of organizational preparedness before adoption takes place. This repositioning is further strengthened by incorporating ORC-related change constructs, which is theoretically consistent with prior work showing that successful innovation adoption depends not only on technological and environmental conditions, but also on the organization's preparedness to support and absorb change (Jöhnk; Weißert; Wyrtki, 2021; Snyder, 2001; Weiner, 2009). In this sense, the study bridges adoption theory and change-readiness theory, broadening the conceptualization of blockchain readiness beyond technology-centered conditions alone.

Third, the study advances the conceptualization of blockchain readiness in Supply Chains by framing it as a threshold-sensitive and interdependent condition. Prior readiness research has widely adopted multidimensional models incorporating technological, organizational, process, and environmental factors, but has offered limited theorization about how these dimensions jointly shape readiness (Khin; Kee, 2022; Monshizadeh *et al.*, 2023; Pacchini *et al.*, 2019; Pirola; Cimini; Pinto, 2020). The present study argues that in blockchain-enabled Supply Chains, readiness is not adequately captured by a purely additive logic because critical deficiencies in one domain may limit the viability of adoption, regardless of strengths elsewhere. This perspective better reflects the systemic and relational character of blockchain adoption, where preparedness depends on the minimum coherence of multiple interconnected conditions.

Fourth, the study contributes to the technology adoption literature by positioning pre-adoption readiness as a theoretically meaningful and empirically assessable stage in the technology adoption trajectory. Mainstream adoption frameworks such as TOE and TAM have primarily focused on explaining adoption decisions and post-adoption outcomes, with comparatively limited attention to the preparatory conditions that shape whether organizations can realistically move from intention to implementation (Jöhnk; Weißert; Wyrtki, 2021; Lokuge *et al.*, 2019). By developing and validating an artifact that makes these preparatory conditions explicit and measurable, this study provides a theoretical bridge between adoption antecedents and adoption readiness as a distinct organizational state. Furthermore, by demonstrating that readiness in blockchain-enabled Supply Chain networks is inherently interorganizational, shaped not only by internal capabilities but also by the alignment of external Supply Chain conditions, the study highlights that technology adoption in networked settings involves a broader process of socioorganizational transformation. In such contexts, readiness is not a fixed threshold that individual firms can achieve in isolation, but a dynamic condition that evolves through coordinated development across organizational boundaries, with implications for how Supply Chain networks govern, sequence, and sustain technology adoption over time.

Overall, the study advances theory by framing blockchain readiness in Supply Chains not as a simple accumulation of favorable conditions, but as a structured, interdependent pre-adoption state shaped by the alignment of technological, organizational, and interorganizational readiness.

7.5.3 Methodological contributions

Methodologically, our study contributes by offering a more traceable, scientifically documented, and design-oriented pathway for developing readiness artifacts than is commonly found in the RM literature. Prior research has pointed to substantial disagreement regarding how readiness and maturity models should be structured (Pacchini *et al.*, 2019), as well as to the scarcity of scientifically developed and empirically validated models in digital transformation contexts (Wagire *et al.*, 2021). Felippes *et al.* (2022) further note that several existing models do not clearly specify essential elements such as dimension levels, enablers, variables, stages, assessment layers, or evaluation logic, while many others remain insufficiently documented or weakly validated for practical benchmarking purposes.

These broader limitations are also visible in blockchain-specific readiness research. Although Irannezhad *et al.* (2021) and Balasubramanian *et al.* (2021) provide approaches that are substantively close to the present study, the former relies on analytically demanding expert-driven procedures, whereas the latter remains primarily qualitative and case-based rather than operationalized as a standardized organizational self-assessment instrument. Against this backdrop, the present study provides a more explicit and auditable development pathway by combining source triangulation, internal consolidation, external expert refinement, formative evaluation of both the questionnaire and the fuzzy rule base, and pilot instantiation under near-real conditions. Compared with many existing readiness approaches, this development logic offers stronger methodological defensibility by enhancing conceptual adequacy, internal consistency, transparency, and replicability, while also supporting adaptation to other readiness domains.

A further methodological contribution lies in the level of scientific documentation provided throughout the artifact-development process, including detailed information (Appendices B-D) that make explicit the derivation of dimensions, the refinement of items, the construction of the fuzzy rule base, and the application procedures of the instrument. In DSR, such documentation is not merely supplementary; it is integral to artifact traceability, auditability, and reproducibility, since artifacts are expected to be developed through explicit, well-documented, and evaluable design procedures. Importantly, the study also demonstrates that methodological rigor does not require a prohibitively complex development process: the artifact was built through multi-method triangulation and iterative refinement in a way that remains methodologically parsimonious and practically manageable, offering a reproducible pathway through which similar readiness artifacts may be developed, scrutinized, and adapted in future research.

The study further contributes by demonstrating that fuzzy inference offers a methodologically appropriate and practically viable mechanism for synthesizing multidimensional readiness in technology adoption contexts. Readiness judgments are typically gradual and partly linguistic rather than sharply delimited, making purely additive scoring insufficient to capture the non-linear interactions across adoption conditions. By embedding a Mamdani-type fuzzy inference system within a standardized self-assessment architecture, the model preserves interpretability, the inference logic remains transparent to researchers and practitioners alike, while enabling bounded compensation across dimensions, preventing critical weaknesses from being fully masked by strengths elsewhere. This combination of interpretability, non-linear aggregation, and practical applicability represents a methodological advance over existing blockchain readiness approaches, and illustrates the broader potential of fuzzy inference as a tool for organization-facing technology adoption assessment. Methodologically, the model therefore advances beyond many existing blockchain readiness approaches by combining stronger standardization and practical applicability with a more realistic and decision-oriented aggregation logic.

7.5.4 Managerial implications

For managers, the model's practical value lies primarily in its preventive and diagnostic roles. It helps organizations determine whether blockchain initiatives should be advanced, postponed, or preceded by further capability development, thereby reducing the likelihood of premature investments, unrealistic expectations, and implementation efforts that exceed the organization's actual preparedness.

The model provides more than an overall readiness classification. It supports managerial decisions by indicating whether blockchain adoption should advance, be postponed, or be preceded by capability-building efforts. Dimension-level scores reveal the main bottlenecks, while item-level results help managers define a readiness roadmap and prioritize actions before implementation. Thus, the model functions as a decision-support tool: it does not automatically prescribe a go/no-go decision, but it makes readiness gaps explicit and actionable for planning, investment prioritization, partner engagement, and periodic reassessment.

Compared with existing blockchain readiness approaches, the model is more directly usable as an organization-facing assessment tool. While prior studies have offered analytically robust or conceptually relevant approaches, they often depend on expert-driven procedures or remain largely qualitative and case-based, which limits their direct use as standardized organizational self-assessment instruments (Balasubramanian *et al.*, 2021; Irannezhad *et al.*, 2021). Other adjacent studies focus on barrier prioritization or individual-level adoption precursors rather than on organization-level diagnosis for managerial decision-making (Behl *et al.*, 2024; Dwivedi *et al.*, 2023).

The model addresses this practical gap by offering a structured questionnaire with closed-ended measurable items, defined respondents, and a standardized response scale. This allows organizations to identify readiness gaps at the item and dimension levels, prioritize improvement efforts, and obtain a consistent overall classification. Although the final classification relies on fuzzy inference, this step can be automated, making the model more manageable in practice than approaches that require intensive expert elicitation or specialized analytical procedures. In this way, the model combines structured diagnosis with practical applicability and supports both one-time evaluation and periodic reassessment of blockchain readiness.

Beyond individual firm-level diagnosis, the model also carries implications for managers operating in interorganizational Supply Chain contexts. Because blockchain adoption in Supply Chains depends on the coordinated alignment of multiple partners, readiness assessment cannot be confined to a single focal organization. The proposed instrument can be applied across Supply Chain partners to map the distribution of readiness conditions within a network, identify the weakest links that constrain collective adoption progress, and support more informed governance decisions about sequencing, investment prioritization, and partner development. In network settings where adoption decisions are inherently interdependent, this capability transforms readiness assessment from an internal diagnostic exercise into a tool for SC-level technology adoption governance.

Furthermore, the model supports managers in navigating the transition from blockchain experimentation to scalable deployment, a critical and frequently undermanaged stage in technology adoption trajectories. By making visible which conditions are already in place and which remain underdeveloped, the instrument enables organizations to move beyond vague aspirations toward structured, evidence-based adoption planning. This is particularly relevant in contexts where blockchain initiatives have stalled at the pilot stage not because the technology is unavailable, but because the organizational and interorganizational foundations for scaling have not been systematically assessed or developed. Used periodically, the model can also function as a progress-tracking mechanism, allowing managers to monitor how readiness evolves over time and adjust capability-building efforts accordingly.

7.6 Conclusion

This study set out to develop and validate a RM for blockchain adoption in Supply Chain contexts. In doing so, it responds to a broader challenge in technology adoption research: understanding what conditions organizations must develop before a transformative technology can be scaled beyond early experimentation. In response to this objective, it produced a final artifact that combines three complementary elements: a TOE-based assessment instrument, a set of 26 readiness requirements operationalized through standardized item-level descriptors on a 0–5 progression scale, and an interpretable fuzzy inference engine for global readiness classification. Taken together, these elements translate blockchain readiness into a structured and actionable organizational assessment, enabling firms to move beyond abstract discussions of adoption challenges toward a more systematic diagnosis of their pre-adoption conditions.

The study is particularly relevant because blockchain initiatives in Supply Chains often fail to advance not only due to technological limitations, but also because the organizational and interorganizational conditions required for adoption are either insufficiently developed or insufficiently understood. In such contexts, the absence of a structured pre-adoption diagnosis increases the likelihood of premature investments, unrealistic expectations, fragmented implementation efforts, and initiatives that remain confined to exploratory or pilot stages. By addressing this gap, the proposed RM provides a more grounded basis for assessing whether a firm is actually prepared to move forward with blockchain-related initiatives in Supply Chain settings.

Beyond producing a practical assessment artifact, the study also contributes by showing that blockchain readiness in Supply Chain should be understood as a multidimensional and interdependent pre-adoption condition. The model captures this complexity by combining diagnostic detail at the item and dimension levels with a global readiness result that preserves interpretability while avoiding simplistic additive logic. As a result, the artifact supports not only the identification of readiness gaps, but also the prioritization of capability-building efforts and the interpretation of how different conditions jointly shape adoption preparedness. In this sense, the study contributes to a more deliberate, transparent, and analytically grounded understanding of blockchain readiness in organizational settings.

From a practical standpoint, the model offers firms a structured way to evaluate their current situation before engaging more deeply in blockchain initiatives. By clarifying where readiness is stronger and where it remains insufficient, the model can support more focused managerial action, more realistic planning, and better alignment between organizational capabilities and adoption ambitions. Its questionnaire-based structure also favors practical diagnosis at the item and dimension levels, while the overall readiness classification can be supported through automated scoring routines, which increases its potential for repeated organizational use over time.

This study has some limitations, which also open important avenues for future research. First, although the artifact was developed and refined through iterative expert-based evaluation and a pilot application, its empirical instantiation was limited to a single organizational setting. Future studies could therefore apply the model across multiple firms, sectors, and countries to examine its broader applicability, compare readiness profiles across different Supply Chain contexts, and identify potential contextual contingencies affecting readiness assessment. Second, the evaluation reported here is predominantly formative in nature, focusing on content adequacy, logical coherence, and practical usability. While this is consistent with the design science orientation of the study, future research could extend the model's evaluation through broader field applications, repeated organizational use, and comparative assessments of how readiness evolves over time. Third, the present study assessed readiness at a single point in time, which limits insight into how readiness conditions develop and align across the stages of blockchain adoption. Future studies could examine how readiness profiles evolve longitudinally within the same organization or across Supply Chain networks, contributing to a more dynamic understanding of the preparatory conditions that enable organizations to move from blockchain experimentation toward scalable deployment. Such longitudinal evidence would strengthen the connection between pre-adoption readiness assessment and actual adoption trajectories, an area that remains underexplored in the technology adoption literature.

Future research may also explore possible refinements of the artifact itself. For example, subsequent studies could test alternative weighting or inference structures, examine how the model performs in different blockchain use cases, or investigate the relationship between pre-adoption readiness and later implementation outcomes. Such developments would not only strengthen the empirical basis of the model, but also contribute to a more cumulative understanding of how blockchain readiness can be assessed and managed in Supply Chain environments.

Overall, the findings suggest that the proposed artifact offers a robust basis for making blockchain readiness more visible, assessable, and actionable in Supply Chain contexts. By integrating a structured assessment instrument with an interpretable fuzzy classification logic, the study advances the possibility of more informed, transparent, and realistic pre-adoption decision-making for organizations considering blockchain initiatives. As blockchain and other distributed technologies continue to reshape the boundaries of Supply Chain collaboration, the ability to assess and build readiness systematically becomes increasingly central to how organizations anticipate, plan, and govern their technology adoption journeys.

8 CONCLUSION

This section concludes the thesis by synthesizing the main findings and contributions of the study. It integrates the results of the four articles to provide a cohesive understanding of blockchain adoption readiness in supply chain networks, and discusses the theoretical, methodological, and practical implications of the research. Finally, it outlines the study's limitations and proposes directions for future research.

8.1 Synthesis of the thesis

This thesis was guided by the following overarching research question: How can readiness for blockchain adoption in supply chain networks be systematically understood, structured, and assessed to support organizational adoption decisions? To address this question, the thesis employed a cumulative research design in which each study contributed a necessary step toward developing the final readiness assessment model.

The first two studies established the thesis's diagnostic basis by identifying the barriers constraining blockchain adoption in supply chain contexts. Article 1 focused on technological barriers, the strategies proposed to mitigate them, and the stages of adoption in which such barriers and strategies emerge. Article 2 complemented this analysis by examining non-technological barriers, their mitigation strategies, and the alignment of these strategies with the needs and characteristics of different stakeholders in the supply chain ecosystem. Together, these studies showed that blockchain adoption is hindered not only by technological limitations, but also by organizational, relational, and ecosystem-level challenges, reinforcing the view that adoption readiness in supply chains is inherently multidimensional.

Building on this diagnostic foundation, Article 3 addressed the methodological problem of how readiness models for emerging digital technologies in Operations and Supply Chain Management should be designed and structured. By proposing a DSR-based reference architecture for readiness model development, this study provided the methodological logic for structuring and developing readiness models with greater rigor and coherence. In this sense, Article 3 did not simply add another layer of analysis; it established the design principles through which dispersed knowledge on readiness assessment could be systematically organized into a coherent model.

Article 4 then integrated insights from previous studies into the development and evaluation of an organizational readiness assessment artifact for blockchain adoption in supply chain networks. Importantly, the artifact was not derived solely from the barriers identified in Articles 1 and 2. Rather, these barriers were first reframed into positive readiness requirements and then combined with readiness requirements identified in the broader literature on emerging digital technologies, as well as with constructs derived from the TOE framework and ORC. In this way, the final model was grounded simultaneously in blockchain-specific adoption challenges, broader readiness knowledge, and consolidated theoretical constructs related to technology adoption and organizational change. These inputs were organized into a theory-grounded readiness model and operationalized into a structured assessment instrument, supported by an interpretable mechanism for aggregating multidimensional readiness into an overall readiness outcome.

Taken as a whole, the thesis advances from diagnosing blockchain adoption barriers in supply chains to deriving and structuring readiness requirements and, ultimately, to developing a validated readiness assessment artifact. Thus, the thesis does not present the final model as an isolated solution, but as the outcome of a progressive and integrative research trajectory in which empirical diagnosis, theoretical structuring, and artifact design are systematically connected.

8.2 Theoretical Implications

The theoretical contribution does not lie in any single study in isolation, but in the cumulative integration of the four studies into a broader explanation of readiness for blockchain adoption in supply chain networks. Taken together, the thesis contributes theoretically by reframing the problem, integrating complementary lenses, and structuring readiness as a coherent pre-adoption construct.

A first contribution is to reframe blockchain adoption in supply chains as a readiness problem rather than merely an adoption problem. Prior research has largely emphasized barriers, enablers, and adoption challenges, showing that blockchain implementation in supply chains is constrained by interrelated technological, organizational, interorganizational, and external barriers (Kouhizadeh; Saberi; Sarkis, 2021). In this sense, the key issue is not only whether blockchain may generate value, but whether organizations and their partners possess the multidimensional conditions necessary for successful adoption (Kouhizadeh; Saberi; Sarkis, 2021; Mathivathanan *et al.*, 2021; Khan *et al.*, 2023). By bringing together the findings of Articles 1 (chapter 4) and 2 (chapter 5) and interpreting them through the broader readiness literature, the thesis shifts the focus from isolated adoption factors toward preparedness for implementation in interorganizational supply chain contexts. This reframing is theoretically relevant because it aligns blockchain adoption with the broader view that readiness concerns the organizational conditions required for effective implementation, rather than simple intention or perceived value alone (Weiner, 2009; Lokuge *et al.*, 2019; Antony; Sony; McDermott, 2023).

A second contribution lies in integrating complementary theoretical lenses to explain blockchain adoption readiness in supply chain networks. Diffusion of Innovations helps explain why adoption challenges emerge across different stages of the innovation-decision process, highlighting the temporal nature of adoption rather than treating it as a single decision point (Rogers, 2003). Stakeholder Theory adds an interorganizational and ecosystem-level perspective by emphasizing that organizational outcomes are shaped by multiple groups that affect or are affected by organizational action, which is particularly relevant in supply chains where adoption conditions depend on the engagement and coordination of diverse actors rather than on the focal firm alone (Freeman, 1984). In turn, the TOE framework helped structure the readiness requirements into technological, organizational, and environmental dimensions, while also informing the incorporation of adoption-related constructs across these dimensions (DePietro *et al.*, 1990; Tornatzky; Fleischer, 1990; Baker, 2012). Organizational Readiness for Change complements this view by clarifying that readiness is not only structural, but also collective, depending on organizational members' shared commitment to implement change and their shared belief in their capability to do so effectively (Weiner, 2009). By combining these lenses across the four studies, the thesis contributes to a more structured and theoretically robust explanation of blockchain adoption readiness in supply chain networks, extending the debate beyond perspectives that focus solely on technological conditions.

A third theoretical contribution lies in conceptualizing blockchain adoption readiness in supply chain networks as an interorganizational condition rather than a purely firm-level condition. Prior research has shown that blockchain adoption in supply chains is shaped by intra-organizational, interorganizational, technical, and external-environmental factors, and that critical barriers such as lack of information sharing, trust-related difficulties, and coordination problems emerge across relationships among supply chain actors rather than within the focal firm alone (Ahmed; MacCarthy, 2022; Kouhizadeh *et al.*, 2021; Khan *et al.*, 2023). In this sense, this study shows that readiness for blockchain adoption in supply chain networks depends not only on internal organizational preparedness, but also on the alignment of conditions across actors, interfaces, and external contexts. By doing so, it extends the theorization of readiness beyond the focal organization and offers a conceptualization better suited to the relational and ecosystem-based nature of blockchain adoption in supply chains.

8.3 Methodological Implications

The methodological contribution lies less in any single method or technique and more in the cumulative research design through which the final readiness artifact was developed. Taken together, the four studies contribute methodologically by making explicit a progressive pathway linking diagnosis, conceptual structuring, and artifact development within a coherent research trajectory.

A first methodological contribution is to demonstrate a cumulative pathway for developing readiness assessment models in emerging-technology contexts. This contribution is relevant because prior work has emphasized the value of explicit and rigorous procedures for model development, while also highlighting how incomplete methodological documentation weakens reproducibility, reliability, and cumulative knowledge building (Becker *et al.*, 2009). It is also consistent with the broader logic of design science, according to which knowledge about a problem domain can be progressively transformed into an artifact through structured cycles of problem definition, design, development, demonstration, and evaluation (Hevner *et al.*, 2004; Peffers *et al.*, 2007). This thesis arrived at that contribution by connecting, across the four studies, review-based diagnosis of blockchain adoption barriers, the methodological structuring of readiness model design, and the subsequent development and evaluation of the final artifact. In this sense, the thesis contributes methodologically by showing how dispersed explanatory knowledge can be progressively organized into a design-oriented pathway for developing readiness models.

A second methodological contribution lies in operationalizing multidimensional readiness into an assessable, interpretable logic. This contribution is relevant because the readiness literature has long treated readiness as a multidimensional condition that can support benchmarking and cumulative research, yet the ways in which these dimensions are translated into assessable structures and overall readiness outcomes remain uneven across existing models (Lokuge *et al.*, 2019; Antony; Sony; McDermott, 2023). Related work has also shown the value of organizing readiness requirements into structured models and of examining the relationships among readiness dimensions rather than treating them as isolated factors (Monshizadeh *et al.*, 2023). This thesis arrived at that contribution by deriving readiness requirements from multiple sources, organizing them into a structured instrument, and complementing that instrument with a fuzzy-logic-based aggregation mechanism that synthesizes multidimensional assessments into an overall readiness outcome. Methodologically, the contribution lies not in any single procedure in isolation, but in showing how cumulative studies can connect requirement derivation, model structuring, and interpretive aggregation within a coherent assessment design.

8.4 Practical Implications

At the practical level, this study contributes by providing an assessment-oriented response to a problem that organizations increasingly face when considering blockchain adoption in supply chain contexts: determining whether they are sufficiently prepared to move from interest and experimentation to concrete adoption efforts. Rather than assuming that recognition of blockchain's potential value is sufficient to justify implementation, the thesis provides a structured basis for evaluating whether the necessary technological, organizational, and external conditions are in place before undertaking substantial investments and organizational changes.

A first practical contribution is to support organizational decision-making in pre-adoption contexts. The Readiness Model developed in this thesis offers firms a structured way to determine whether to initiate, postpone, or precede adoption efforts with additional preparation. In this sense, the practical value of the thesis is not limited to determining whether a company is ready; it also lies in helping decision-makers avoid premature implementation efforts in situations where critical conditions remain underdeveloped. For organizations operating in supply chain environments, where blockchain adoption often depends on coordination with multiple internal functions and external partners; such a pre-adoption assessment can reduce uncertainty and improve the quality of strategic and operational decisions.

A second practical contribution lies in translating the abstract idea of readiness into a usable assessment logic. By organizing readiness requirements into a structured instrument and complementing them with an interpretable aggregation mechanism, the thesis provides organizations with a way to diagnose strengths and weaknesses across different readiness dimensions while still obtaining an overall readiness outcome. This is particularly useful in managerial settings because it allows firms not only to position themselves relative to their current state but also to identify priority areas for improvement. In practical terms, the model can support action planning by showing where readiness is weakest, where efforts should be concentrated, and where apparently favorable conditions may still be offset by deficiencies in other dimensions.

A third practical contribution lies in reducing the gap between conceptual readiness discussions and organizational use. Prior studies have often identified barriers, proposed broad readiness frameworks, or relied on analytically demanding approaches requiring expert-driven elicitation, causal mapping, and weighting procedures, which may limit their direct use by firms without methodological support (Irannezhad *et al.*, 2021; Balasubramanian *et al.*, 2021). Other studies have focused on adjacent issues, such as prioritizing blockchain readiness challenges in specific domains, rather than providing a repeatable organization-facing assessment instrument (Dwivedi *et al.*, 2023). Prior work on readiness and maturity models has highlighted shortcomings in model completeness, clarity, and practical applicability, while also demonstrating the value of self-diagnostic approaches for organizational use (Felippes *et al.*, 2022; Ramanathan; Samaranayake, 2022). Against this backdrop, the practical value of this thesis lies in providing a structured, interpretable readiness assessment instrument that organizations can use as a user-friendly self-assessment tool before implementation begins.

The Readiness Model developed in this thesis is best understood as a decision-support tool for the pre-adoption phase. After the organization has used it to assess its preparedness and decided to proceed with implementation, the next practical need is no longer readiness diagnosis, but capability development and progress monitoring, an area more closely aligned with maturity-oriented frameworks and implementation roadmaps (Pacchini *et al.*, 2019; Schumacher *et al.*, 2016; Ramanathan; Samaranayake, 2022). In this sense, the present model can serve as an entry point for a broader assessment journey in which readiness precedes and potentially connects with maturity-oriented evaluation over time (Demir *et al.*, 2022).

8.5 Limitations and future research agenda

The limitations of this thesis should be acknowledged, as they also indicate important opportunities for future research. A first limitation concerns the scope of empirical validation for the final artifact. Although the readiness model was refined through expert evaluation and examined through a pilot application in a real organizational setting, its validation remains limited at the thesis level. The pilot provided important evidence of applicability, interpretability, and practical relevance, but it does not support broader claims about transferability across industries, countries, or different supply chain configurations.

A second limitation lies in the contextual specificity of the thesis. The final readiness model was intentionally developed for blockchain adoption in supply chain networks, which strengthens its conceptual coherence and practical relevance, but also limits direct generalization to other emerging technologies or non-supply-chain contexts. In addition, the model was deliberately designed to assess organizational readiness for blockchain adoption in supply chain environments more broadly, rather than for a single blockchain property or a narrowly defined application. Although blockchain may be adopted with a more specific focal objective in some contexts, its potential value in supply chains is not limited to a single feature, and different firms may prioritize different expected benefits depending on their position, processes, and strategic concerns. This broader design strengthens the model's general applicability in blockchain-enabled supply chain contexts, but it also means the thesis does not examine in depth how readiness may vary across highly specific blockchain use cases.

A further limitation concerns the operational logic used to synthesize multidimensional readiness into an overall readiness outcome. Although the aggregation mechanism was designed to balance interpretability and analytical robustness, it reflects a particular set of design choices. Alternative aggregation logics may also be possible and deserve further examination.

These limitations suggest several directions for future research. First, the RM should be applied and evaluated in a broader range of empirical settings, including different industries, countries, and supply chain structures, to assess its transferability, robustness, and contextual sensitivity. Second, future studies could extend the logic developed here to other emerging digital technologies in operations and supply chain management, examining which readiness requirements remain stable across technologies and which are specific to blockchain adoption. Within the blockchain domain itself, future research could also investigate how adoption readiness varies across more narrowly defined application contexts, such as traceability, provenance verification, transparency enhancement, or smart contract deployment. Such studies could examine whether specific use cases demand distinct readiness requirements or different weighting of technological, organizational, and environmental conditions. Third, future research could explore readiness assessment beyond the focal organization, investigating how readiness might be conceptualized and measured at the level of dyads, partnerships, or broader supply chain networks. Fourth, future studies could compare the current aggregation logic with alternative approaches for synthesizing multidimensional readiness, including different fuzzy configurations or other forms of decision-support modeling.

A final avenue for future research concerns the continuity between readiness and maturity. While this thesis focuses on pre-adoption readiness, the literature suggests that readiness and maturity can be understood as related stages within a broader transformation journey. De Carolis *et al.* (2017), for example, explicitly argue that the terms readiness and maturity are relative and related, distinguishing readiness as the capability to deploy a concept and maturity as the extent to which that concept has been employed over time. In this sense, future research could investigate how the readiness logic developed here might be connected to a compatible maturity framework, so that readiness functions as an entry stage for a more continuous assessment of implementation progress and capability development over time. More specifically, future studies could focus on developing maturity models for blockchain adoption in supply chain contexts, thereby ensuring a smoother transition from pre-adoption diagnosis to post-adoption evolution. Such work could help clarify how organizations move from being ready to adopt blockchain to becoming progressively more mature in its implementation and use.

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APPENDIX A - Studies analysed in SLR (Article 2 – Chapter 5)

Reference number	Authors	Year	Country	Journal
[8]	Babich and Hilary	2019	USA	Manufacturing & Service Operations Management
[124]	Wong *et al.*	2020	Malaysia	International Journal of Production Research
[10]	Bai and Sarkis	2020	China	International Journal of Production Research
[18]	Chang, Iakovou and Shi	2020	USA	International Journal of Production Research
[135]	Ziolkowski, Miscione and Schwabe	2020	Switzerland	Journal of Management Information Systems
[47]	Iftekhar *et al.*	2020	China	Journal of Food Quality
[132]	Zamani and Giaglis	2017	UK	Industrial Management & Data Systems
[97]	Kamble, Gunasekaran and Arha	2019	India	International Journal of Production Research
[99]	Saberi *et al.*	2019	USA	International Journal of Production Research
[127]	Wang *et al.*	2019	UK	International Journal of Production Economics
[45]	Huang *et al.*	2019	China	IEEE Transactions on Industrial Informatics
[125]	Wong *et al.*	2020b	Malaysia	International Journal of Information Management
[54]	Khan *et al.*	2020	Pakistan	Sustainable Cities and Society
[26]	Di Vaio and Varriale	2020	Italy	International Journal of Information Management
[12]	Bodkhe *et al.*	2020	India	IEEE Access
[62]	Kouhizadeh, Saberi and Sarkis	2021	USA	International Journal of Production Economics
[133]	Zhao *et al.*	2019	UK	Computers in Industry
[100]	Saberi, Kouhizadeh and Sarkis	2019	USA	IEEE Engineering Management Review
[77]	Meng *et al.*	2018	Denmark	IEEE Access
[24]	De Giovanni	2020	Italy	International Journal of Production Economics
[93]	Queiroz and Fosso Wamba	2019	Brazil	International Journal of Information Management
[32]	Fosso Wamba *et al.*	2020	France	Production Planning & Control
[98]	Kamble, Gunasekaran and Sharma	2020	India	International Journal of Information Management
[122]	Wan, Huang and Holtskog	2020	Norway	IEEE Access
[128]	Yadav *et al.*	2020	India	Resources, Conservation & Recycling
[91]	Pournader *et al.*	2020	Australia	International Journal of Production Research
[88]	Pereira, Tavalaei and Ozalp	2019	UK	Technological Forecasting & Social Change
[40]	Hackius and Petersen	2020	Germany	IEEE Access
[71]	Lu *et al.*	2019	USA	IEEE Access
[33]	Fosso Wamba, Queiroz and Trinchera	2020	France	International Journal of Production Economics
[34]	Frizzo-Barker *et al.*	2020	Canada	International Journal of Information Management
[38]	Gonczol *et al.*	2019	Denmark	IEEE Access
[76]	Mendling *et al.*	2018	Austria	ACM Transactions on Management Information Systems
[4]	Al-Jaroodi and Mohamed	2019	USA	IEEE Access
[29]	Farooque *et al.*	2020	Pakistan	Computers & Industrial Engineering
[3]	Ahl *et al.*	2020	Japan	Renewable and Sustainable Energy Reviews
[73]	Makridakis and Christodoulou	2019	Cyprus	Future Internet
[36]	Galvez, Mejuto and Simal-Gandara	2018	Spain	Trends in Analytical Chemistry
[25]	Demir, Turetken and Mashatan	2020	Canada	IEEE Computer Society
[6]	Andoni *et al.*	2019	UK	Renewable and Sustainable Energy Reviews
[121]	Viriyasitavat, Anuphaptrirong and Hoonsopon	2019	Thailand	Journal of Industrial Information Integration

Reference number	Authors	Year	Country	Journal
[30]	Feng *et al.*	2020	China	Journal of Cleaner Production
[78]	Merkaš, Perkov and Bonin	2020	Croatia	International Journal of E-Services and Mobile Applications
[113]	Tiscini	2020	Italy	Management Decision
[69]	Lee, Azamfar & Sing	2019	USA	Manufacturing Letters
[96]	Rogerson and Parry	2020	UK	Supply Chain Management
[43]	Hastig and Sodhi	2020	UK	Production and Operations Management
[115]	Upadhyay	2020	India	International Journal of Information Management
[14]	Bragadeesh and Umamakeswari	2018	India	International Journal of Engineering & Technology
[101]	Schimidt and Wagner	2019	Sweden	Journal of Purchasing and Supply Management
[65]	Kurpjuweit *et al.*	2019	Switzerland	Journal of Business Logistics
[117]	Van Hoek	2020	USA	Supply Chain Management-An International Journal
[11]	Biswas and Gupta	2019	India	Computers & Industrial Engineering
[23]	De Fillipi *et al.*	2020	France	Technology in Society
[37]	Gausdal, Czachorowski and Solesvik	2018	Norway	Sustainability
[48]	Wang *et al.*	2017	Australia	Frontiers of Engineering Management
[86]	Padmavathi and Rajagopalan *et al.*	2019	India	International Journal of Innovative Technology and Exploring Engineering
[110]	Tandon *et al.*	2020	Finland	Computers in Industry
[67]	Lakshmi and Sricharan	2019	India	International Journal of Recent Technology and Engineering
[28]	Drljevic, Aranda and Stantchev	2020	Spain	Computer Standards & Interfaces
[21]	Ghode *et al.*	2019	India	Journal of Enterprise Information Management
[18]	Chen *et al.*	2020	China	Information Systems and e-Business Management
[42]	Hang, Choi and Kim	2019	South Korea	Electronics
[52]	Kamilaris, Fonts and Prenafeta-Boldὐ	2019	Spain	Trends In Food Science & Technology
[106]	Sternberg, Hofmann and Roeck	2020	USA	Journal of Business Logistics
[70]	Ching-Fu Lin	2019	Taiwan	Food and Drug Law Journal
[72]	Mackey *et al.*	2019	USA	BMC Medicine
[46]	Hughes *et al.*	2019	UK	International Journal of Information Management
[7]	Attaran and Gunasekaran	2019	USA	International Journal of Applied Decision Sciences
[41]	Hald and Kinra	2019	Denmark	International Journal of Physical Distribution & Logistics Management
[53]	Karapetyan *et al.*	2019	USA	International Journal of Economics and Business Administration
[102]	Sheel and Nath	2019	India	Management Research Review
[20]	Cole, Stevenson and Aitken	2019	UK	Supply Chain Management-An International Journal
[5]	Allen *et al.*	2019	Australia	Asia and the Pacific Policy Studies
[109]	Tan *et al.*	2020	China	Sustainability
[114]	Tseng *et al.*	2018	Taiwan	International Journal of Environmental Research And Public Health
[61]	Kouhizadeh, Zhu and Sarkis	2020	USA	Production Planning & Control
[82]	Morkunas, Paschen and Boon	2019	Sweden	Business Horizons
[68]	Lambourdiere and Corbin	2020	France	Worldwide Hospitality and Tourism Themes
[92]	Prasad *et al.*	2018	India	Journal of Advances in Management Research
[19]	Clohessy and Acton	2019	Ireland	Industrial Management & Data Systems
[59]	Kodym, Kubáč and Kavka	2020	Czech Republic	Open Engineering
[39]	Grigoreva, Garifova and Polovkina	2019	Russia	International Journal on Emerging Technologies
[120]	Vilkov and Tian	2019	China	International Forestry Review
[105]	Srivastava et al	2019	India	International Journal of Scientific and Technology Research

Reference number	Authors	Year	Country	Journal
[13]	Achilleas Boukis	2019	UK	Journal of Product and Brand Management
[16]	Chung-Shan Yang	2019	Taiwan	Transportation Research Part E-Logistics and Transportation Review
[85]	Nayak and Dhaigude	2019	India	Cogent Economics and Finance
[1]	Abdullah and Ibrahim	2020	Iraq	Indonesian Journal of Electrical Engineering and Computer Science
[79]	Meyer, Kuhn and Hartmann	2019	Germany	Computers & Industrial Engineering
[116]	Van Hoek	2019	USA	International Journal of Operations & Production Management
[31]	Fitzhan *et al.*	2020	Indonesia	International Journal of Emerging Trends in Engineering Research
[15]	Brilliantova and Thurner	2018	Russia	Technology In Society
[9]	Babkin *et al.*	2018	Russia	International Journal of Engineering and Technology (UAE)
[134]	Zheng, Zhu and Si	2019	China	Applied Sciences-Basel
[44]	Howson	2020	UK	Marine Policy
[57]	Klöckner *et al.*	2020	Switzerland	Research-Technology Management
[104]	Shojaei, Wang and Fener	2020	USA	Built Environment Project and Asset Management
[50]	Jawaji *et al.*	2020	India	International Journal of Advanced Science and Technology
[83]	Mundra	2018	USA	Information Services and Use
[58]	Ko, Lee and Ryu	2018	South Korea	Sustainability
[123]	White	2017	UK	Strategic Change-Briefings in Entrepreneurial Finance
[35]	Fu and Zhu	2019	China	Tehnicki Vjesnik-Technical Gazette
[60]	Kouhizadeh, Sarkis and Zhu	2019	USA	Applied Sciences-Basel
[103]	Sheel and Nath	2020	India	International Journal of Business Innovation and Research
[22]	Ghode *et al.*	2020	India	Journal of Manufacturing Technology Management
[89]	Perez *et al.*	2020	Philippines	International Journal of Scientific and Technology Research
[27]	Dierksmeier and Seele	2018	Germany	Business Ethics-A European Review
[129]	Yli-Huumo *et al.*	2016	Finland	PLoS one
[75]	Maslin, Watt and Yong	2019	Australia	Journal of ICT Standardization
[80]	Min	2018	USA	Business Horizons
[130]	Yoo and Won	2018	South Korea	Sustainability
[119]	Vatankhah Barenji *et al.*	2019	China	International Journal of Production Research
[66]	Lacity	2018	USA	MIS Quarterly Executive
[55]	Khezr *et al.*	2019	Canada	Applied Sciences
[118]	Varghese, Kavitha and Michael	2019	India	International Journal of Innovative Technology and Exploring Engineering
[108]	Sydowar, Sunny and Coffman	2020	Italy	Journal of Business Venturing Insights
[74]	Mariappan	2019	India	International Journal of Recent Technology and Engineering
[131]	Younan *et al.*	2020	Egypt	Measurement: Journal of the International Measurement Confederation
[49]	Jain *et al.*	2020	India	Journal of Enterprise Information Management
[84]	Murari and Ravishankar	2020	India	International Journal of Advanced Trends in Computer Science and Engineering
[81]	Moraes and Cernev	2020	Brazil	Journal of Information Technology Teaching Cases
[94]	Yang *et al.*	2020	Australia	Automation in Construction
[87]	Vinay Reddy	2019	India	International Journal of Engineering and Advanced Technology
[63]	Kumar, Liu and Shan	2020	USA	Decision Sciences
[56]	Kim	2020	South Korea	Journal of System and Management Sciences
[95]	Rane and Narvel	2019	India	Benchmarking
[107]	Sukheja *et al.*	2019	India	Journal of Advanced Research in Dynamical and Control Systems

Reference number	Authors	Year	Country	Journal
[111]	Tezel *et al.*	2020	UK	Frontiers of Engineering Management
[126]	Xu *et al.*	2020	China	Sensors
[90]	Craig Pirrong	2019	USA	Journal of Applied Corporate Finance
[51]	Jiang *et al.*	2019	China	Sensors
[64]	Kuo, Kim and Ohno-Machado	2017	USA	Journal of the American Medical Informatics Association
[2]	Abeyratne and Monfared	2016	UK	International Journal of Research in Engineering and Technology
[136]	Kannan *et al.*	2024	Australia	Business Strategy and the Environment
[137]	Hoang and Huang	2025	Taiwan	Management of Environmental Quality: An International Journal
[138]	Tangsakul and Sureeyatanapas	2024	Thailand	Journal of Open Innovation: Technology, Market, and Complexity
[139]	Wong *et al.*	2023	Malaysia	IEEE Transactions on Engineering Management
[140]	Vern	2023	India	Operations Management Research
[141]	Quayson *et al.*	2024	China	Operations Management Research
[142]	Mathivathanan *et al.*	2021	India	International Journal of Production Research
[143]	Mangla *et al.*	2021	India	Business Strategy and the Environment
[144]	Heidary-Dahooie 22	2022	Iran	Technology in Society
[145]	Kumar *et al.*	2022	India	Technovation
[146]	Balci and Surucu-Balci	2021	UK	Transportation Research Part E
[147]	Moretto and Macchion	2022	Italy	Operations Management Research
[148]	Khan *et al.*	2022	India	Benchmarking: An International Journal
[149]	Friedman and Ormiston	2022	Netherlands	Technological Forecasting & Social Change
[150]	Yousefi and Tosarkani	2024	Canada	Engineering Applications of Artificial Intelligence
[151]	Ali *et al.*	2025	Bangladesh	Industrial Management & Data Systems
[152]	Virmani and Singh	2024	India	International Journal of Quality & Reliability Management
[153]	Vafadarnikjoo *et al.*	2021	UK	Annals of Operations Research
[154]	Benabdellah *et al.*	2023	Morocco	Benchmarking: An International Journal
[155]	Yadav *et al.*	2023	India	International Journal of Production Economics

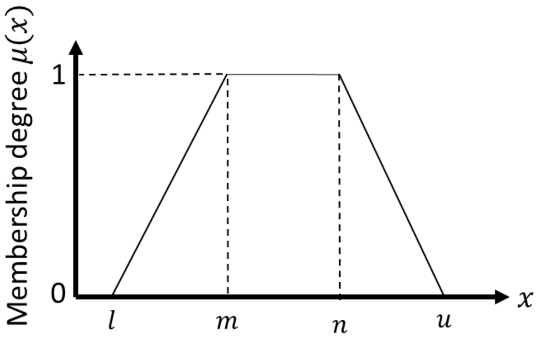
Source: Elaborated by author.

APPENDIX B – Membership functions

Below we present the triangular and trapezoidal membership functions used in the study.

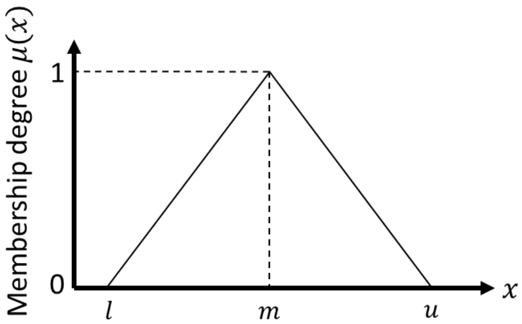
Let l, m, n and u be real numbers with $l < m < n < u$, then the trapezoidal fuzzy number represented in Figure B.1 is given by Eq. 1, in which m and n represents the maximum point in the membership degree and outside of the range $[l, u]$, the membership degree of is null. In the same way, the triangular fuzzy number presented by Figure B.2 can be defined using Eq. 2.

Figure B.1 - Trapezoidal fuzzy number



$$\mu(x) = \begin{cases} 0, & x_i < l, \\ \frac{x_i - l}{m - l}, & a \leq x_i \leq m, \\ 1, & m \leq x_i \leq n \\ \frac{u - x_i}{u - n}, & n \leq x_i \leq u, \\ 0, & x_i > u. \end{cases} \quad (1)$$

Figure B.2 - Triangular fuzzy number



$$\mu(x) = \begin{cases} 0, & x \leq l \\ \frac{x - l}{m - l}, & l \leq x \leq m \\ \frac{x - u}{m - u}, & m \leq x \leq u \\ 0, & x \geq u \end{cases} \quad (2)$$

APPENDIX C – Instrument (Questionnaire)

The complete questionnaire, as finalized after formative validation and pilot application, is presented below.

Blockchain Adoption Readiness Questionnaire (Online)
INFORMED CONSENT FORM (ICF)
Research title: Blockchain Adoption Readiness in Supply Chain Networks: A Design Science–Based Assessment Model
Researcher: Katherine Kaneda Moraes – Graduate Program in Production Engineering (PPGEP–UFSCar)
Email: katherinemoraes@ufgd.edu.br
Supervisor: Gilberto Miller Devós Ganga (UFSCar)
Co-participating institution (data collection site): *For internal research purposes only; will not be disclosed in publications if agreed.*

1. Invitation and objectives

You are invited to participate in an academic research study aimed at assessing organizational readiness for the adoption of blockchain technology through a structured questionnaire with closed-ended questions. The study seeks to map technological, organizational, and external environment/supply chain conditions required for the future adoption of blockchain.

2. What participation involves (procedures)

If you agree to participate:
You will complete one questionnaire related to your area of expertise (Technological, Organizational, or External Environment/Supply Chain).
The questions are closed-ended and use a Likert-type scale.
Estimated completion time:
Technological dimension: 5–10 minutes
Organizational dimension: 15–25 minutes
External Environment dimension: 5–10 minutes

3. Risks and discomforts

This study presents minimal risk. No foreseeable risks are expected beyond those encountered in everyday life. However, you may experience minor discomfort when answering questions related to organizational practices and conditions. You may discontinue your participation at any time, without any penalty or negative consequences.

4. Expected benefits

There is no guaranteed direct benefit to participants. As a potential benefit, the organization may receive a readiness assessment (by dimension), which can support planning, prioritization of actions, and decision-making related to preparation for emerging technologies.

5. Confidentiality, privacy, and data use

This questionnaire is designed to not collect personally identifiable information (such as name, personal identification numbers, or personal email addresses).

Only general profile information may be collected in broad categories (e.g., functional area, level of responsibility, years of experience), solely for general characterization of respondents.

The results will be analyzed in aggregated form and presented in reports and academic outputs without individual identification. Confidentiality is a core principle of this research: all information provided in confidence will be safeguarded and protected against unauthorized disclosure.

Data storage and security: Data will be stored in a digital environment with access restricted to the principal investigator.

Publications: Research findings may be used in thesiss/thesis, academic articles, and conference presentations. In all cases, results will be presented in aggregated form, and no information that could directly or indirectly identify the organization (company) or participants will be disclosed.

6. Voluntary participation and right to withdraw

Your participation is voluntary. You may refuse to participate or withdraw at any time, without penalty or any form of disadvantage.

7. Statement of consent

By selecting "**I AGREE**" and proceeding, you declare that you:

Have read and understood the information above;

Have had the opportunity to ask questions;

Voluntarily agree to participate in this research.

( ) I AGREE TO PARTICIPATE

( ) I DO NOT AGREE *(this option will close the form)*

TECHNOLOGICAL DIMENSION

Recommended respondent: IT manager, systems manager, digital infrastructure manager, or equivalent.

This form assesses an organization's technological readiness for blockchain adoption. It is part of a broader blockchain adoption readiness instrument structured into three dimensions: Technological, Organizational, and External Environment (Supply Chain). This form includes only Items 1–5. Please answer based on the organization's current situation.

Item 1: IT Infrastructure for Data Collection

This item assesses the extent to which the company has infrastructure and access to smart products and devices (e.g., RFID, Electronic Product Codes – EPC, embedded sensors, connectivity devices, real-time event streaming, NFC, and information capture systems) that support the integration between physical and digital environments and enable the implementation of blockchain.

Score	How is the IT INFRASTRUCTURE FOR DATA COLLECTION in your company?
0	There are no smart devices or infrastructure for automated data collection. Data are collected manually (e.g., on paper or in local records), and there is no automatic data flow from physical processes into the company's digital systems.
1	Basic digital data collection methods are in place (e.g., spreadsheets, barcode scanning), but no smart devices or automation. Data capture is manual and disconnected from core systems.
2	Initial experimentation with smart devices (e.g., RFID tags or sensors) is conducted in limited areas, typically through pilots or proofs of concept. Implementations are isolated, without standardization, integration with enterprise systems (e.g., ERP/WMS/MES), or formal planning related to blockchain adoption.
3	Smart devices (e.g., RFID, sensors) are deployed in key processes, enabling partial automation of data collection. Integration with enterprise systems exists but remains fragmented or semi-manual.
4	Data collection infrastructure is fully automated and integrated across internal systems. Technical and governance requirements for blockchain adoption (e.g., data standards, security protocols) are defined and operational.
5	The data collection infrastructure is fully integrated and designed to support seamless blockchain deployment. Data capture and transmission are automated and standardized, enabling rapid onboarding of blockchain solutions. The organization maintains simulation or pilot environments to test data integration with blockchain and can quickly adapt systems and processes to new requirements.

Item 2: IT Infrastructure for Data Communication

This item measures the level of capability and maturity of the company's data communication infrastructure to transmit and exchange digital information across systems, processes, and partners (internal and external) in a reliable and secure manner, with adequate performance in terms of capacity, speed, availability, and stability.

Score	How is the IT INFRASTRUCTURE FOR DATA COMMUNICATION in your company?
0	No infrastructure for digital communication or data exchange. Processes rely on manual or paper-based communication.
1	The organization relies on basic digital communication tools (e.g., email and messaging applications) and simple internal systems for operational data exchange. These solutions are fragmented, lack integration, and do not support the structured and secure data flows required for blockchain readiness.
2	Dedicated platforms for internal data exchange (e.g., ERP modules, EDI systems, or equivalent solutions) are in place, enabling partial integration across departments. However, integration remains limited to specific processes, and data exchange with external partners (e.g., suppliers, customers, logistics providers) still relies on manual or semi-automated methods, such as file sharing via email or portal uploads.
3	Integrated communication systems enable structured and standardized data exchange internally and with selected partners. Basic integration standards and reliability and security mechanisms (e.g., defined interfaces, authentication, and monitoring) are in place; however, support for real-time exchange and advanced governance requirements is still limited.
4	The communication infrastructure supports real-time, secure data exchange across internal and external systems. APIs, standards, and protocols required for blockchain connectivity are defined and tested and aligned with governance requirements, such as security, access control, auditability, and compliance.
5	Communication systems are fully interoperable and configured for blockchain deployment. The organization can rapidly onboard blockchain nodes and partners, supported by automated data synchronization, encryption, and compliance monitoring, and is prepared to efficiently scale these capabilities once blockchain adoption is decided.

Item 3: Security and privacy mechanisms for information

This item measures the level of capability and maturity of the company in protecting information and data against unauthorized access, breaches, loss, and unavailability, as well as in ensuring privacy in data processing, including personal and sensitive data.

Score	How are the SECURITY AND PRIVACY MECHANISMS FOR INFORMATION in your company?
0	There are no formalized information security and privacy mechanisms or guidelines in place. Controls are nonexistent or informal, with no defined standards for data protection and access.
1	Basic security measures (e.g., passwords, antivirus software, and simple access permissions) are in place, and there is initial awareness of data privacy requirements. However, security and privacy controls are weakly standardized, with no structured policies or encryption for sensitive data.
2	Security protocols (e.g., firewalls, role-based access) are applied internally, and compliance with basic standards is monitored. Integration with external partners is minimal.
3	Formalized security and privacy policies are consistently applied across internal systems, with defined encryption standards and data protection controls. Security requirements relevant to blockchain solutions (e.g., cryptographic key management and access control) are identified and documented.
4	Advanced security mechanisms are in place, including cryptographic key management, multi-factor authentication, and privacy controls. The organization is ready to activate and scale blockchain-specific security features once adoption is decided.
5	The security and privacy architecture is fully aligned with blockchain and data protection requirements. Automated key management and compliance monitoring are in place, and the organization is prepared to rapidly scale blockchain-enabled security capabilities once adoption is decided.

Item 4: Interoperability

This item assesses the extent to which the company can integrate systems and exchange data with partners in a standardized, secure, and automated manner, reducing manual rework (e.g., spreadsheets, emails, data re-entry) and ensuring smooth and reliable information flows.

Score	How is the INTEROPERABILITY in your company?
0	Systems are completely isolated. There is no capability for exchanging data between internal applications or with external partners. Processes rely on manual data entry and paper-based documentation.
1	Limited interoperability exists among some internal systems (e.g., ERP exchanging data with a small number of systems via simple export/import routines). Integration with external partners is ad hoc, relying on manual file uploads or email-based data exchange. No standardized protocols or APIs are defined.
2	Basic interoperability is achieved through point-to-point integrations or custom connectors between internal systems. Data exchange with external partners occurs using structured formats (e.g., CSV, XML) but still requires manual steps for export, import, and validation. Integration governance remains informal, with no clearly defined standards or responsibilities.
3	Integration standards (e.g., APIs and/or EDI) are implemented internally, enabling automated data exchange across departments. Secure integration with selected external partners is operational. Blockchain compatibility is under evaluation, and technical integration requirements (e.g., data standards, authentication, and traceability) are documented.
4	Systems are fully interoperable across internal operations and external partners using standardized protocols and secure APIs. The integration architecture supports real-time data exchange and is designed to accommodate blockchain nodes. Governance frameworks for interoperability and data integrity are established, and the organization is interoperable-ready to adopt blockchain once a decision is made.
5	Interoperability is dynamic and automated. The organization can integrate new partners and blockchain nodes with minimal manual configuration, supported by adaptive middleware or integration platforms that accommodate evolving standards. This enables rapid onboarding while maintaining compliance with technical and security requirements of blockchain ecosystems.

Item 5: Reliable and Quality Data

This item assesses the organization's capability to ensure reliable and high-quality input data through measures that ensure information accuracy and consistency, including (where applicable) automated data collection and loading via sensors/IoT (e.g., GPS and RFID) to support the future adoption of blockchain.

Score	How are the RELIABILITY AND QUALITY OF DATA managed in your company?
0	Data management is fragmented. There are no formal rules or processes for ensuring accuracy and consistency. Information is stored in separate systems without integration, and validation is entirely manual or absent.
1	The organization acknowledges the importance of data quality and performs occasional checks for critical information. However, there are no standardized procedures or automated tools, and inconsistencies between systems are common.
2	Basic data quality rules (e.g., mandatory fields, format checks) are documented and applied in some systems. Periodic reviews are conducted to detect errors, but cross-system consistency remains limited.
3	Formal data governance policies exist, and automated validation tools are implemented for key processes. Data quality metrics (accuracy, completeness) are monitored regularly, and blockchain requirements for immutability and traceability are identified but are not yet operationalized.
4	Data quality management is automated across core enterprise systems. Real-time validation ensures data consistency and accuracy before external sharing. Unique identifiers and traceability rules, aligned with blockchain-compatible standards, are applied consistently.
5	Data systems are fully integrated and designed for blockchain deployment. Real-time validation and automated correction mechanisms maintain integrity across internal and external partners. New data sources can be onboarded without manual intervention, ensuring immutability and traceability.

ORGANIZATIONAL DIMENSION

Recommended respondent: innovation manager, transformation manager, strategic planning manager, or equivalent cross-functional leader.

This form assesses an organization's internal readiness for blockchain adoption. It is part of a broader blockchain adoption readiness instrument structured into three dimensions: Technological, Organizational, and External Environment (Supply Chain). This form includes only Items 6–19. Please answer based on the organization's current situation.

Item 6: Financial resources availability for blockchain implementation

This item assesses the organization's ability to secure the necessary financial resources, either internally or through external sources, to cover the initial investments required for blockchain implementation, including infrastructure and specialized service costs.

Score	How are the FINANCIAL RESOURCES FOR BLOCKCHAIN IMPLEMENTATION in your company?
0	No financial resources are allocated for blockchain initiatives. There is no budget plan or investment consideration for this technology.
1	The company acknowledges the need for financial resources for blockchain but has no formal allocation. Discussions occur informally, and any investment would be reactive rather than planned.
2	The organization does not yet have a dedicated budget for blockchain implementation, but potential internal funding sources for initial initiatives (e.g., IT, innovation, digital transformation, or process improvement budgets) have been identified. However, financial resources are not yet integrated into strategic or financial planning.
3	Blockchain implementation is included in the company's financial planning. Dedicated funds are allocated for pilot projects, and cost-benefit analyses are conducted to support decision-making.
4	Financial resources for blockchain are fully integrated into the company's strategic investment plan. Funding covers infrastructure, training, and governance requirements for adoption.
5	The company has a dedicated financial fund or pre-approved budget specifically allocated for blockchain adoption and scaling. This ensures immediate execution when the decision is made. The financial strategy includes contingency planning for rapid expansion and covers infrastructure, training, and governance needs without requiring additional approvals.

Item 7: Financial resources availability for using blockchain technology

This item assesses the organization's ability to obtain and sustain sufficient financial resources, from internal or external sources, to support the recurring costs associated with the ongoing use of blockchain, including expenses related to operations, transactions, upgrades, storage, support, and maintenance. The focus is on long-term financial sustainability rather than on initial implementation investments.

Score	How is the AVAILABILITY OF FINANCIAL RESOURCES FOR USING BLOCKCHAIN TECHNOLOGY in your company?
0	The company has not considered financial implications of blockchain usage (e.g., transaction fees, maintenance costs). No discussions or plans exist.
1	The company acknowledges that blockchain usage will require financial resources (e.g., transaction fees, system updates) but has no formal allocation.
2	Preliminary cost estimates for blockchain usage exist (e.g., transaction fees, integration costs). However, there is no formal allocation of funds, and budgeting is not part of strategic planning.
3	Blockchain-related operational costs are included in financial planning documents. The company has identified potential funding sources and prepared guidelines for cost monitoring, but funds are not yet allocated.
4	A specific budget line or contingency fund for blockchain usage is approved and integrated into the company's financial plan. Resources are earmarked for expected costs such as scalability, compliance, and technical support.
5	The company maintains a dedicated fund or pre-approved budget for blockchain usage, ensuring immediate coverage of operational costs. Financial planning includes provisions for scaling and unforeseen expenses, guaranteeing uninterrupted blockchain operations.

Item 8: Personnel Competence and Development

This item assesses the organization's ability to develop the technical, business, and organizational competencies of its employees to support the future adoption of blockchain, as well as its readiness to provide continuous training, reskilling, and upskilling focused on emerging technologies.

Score	How is PERSONNEL COMPETENCE AND DEVELOPMENT in your company?
0	The company has not considered blockchain-related skills. Employees have no exposure to distributed ledger concepts or related technologies. Training programs focus only on traditional systems.
1	The company acknowledges the need for blockchain-related competencies and has discussed training informally. Some employees have basic knowledge in IT infrastructure, data security, or cloud technologies, which could be extended to blockchain, but no structured programs exist.
2	Preliminary plans for training employees in blockchain fundamentals exist. Employees have participated in courses on digital transformation, cloud computing, or data security, which provide transferable skills, but blockchain-specific topics (e.g., smart contracts, consensus mechanisms) are not addressed systematically.
3	Formal training programs for blockchain-related skills are documented and scheduled. Key employees are identified for upskilling in areas such as blockchain fundamentals, smart contract logic, distributed systems, and supply chain integration. Competence gaps are monitored regularly.
4	Training programs are implemented, and employees in critical roles have completed courses on blockchain concepts and applications. The company has a structured reskilling plan to ensure readiness for deployment when adoption occurs.
5	The company maintains a continuous learning strategy for blockchain and emerging technologies. A dedicated budget and partnerships with training providers exist. Employees possess advanced knowledge in blockchain integration, smart contracts, and governance, enabling immediate execution when adoption is decided.

Item 9: Innovation/Change valence

This item assesses the extent to which members of the organization demonstrate positive attitudes toward change, including motivation, engagement, and appreciation of innovation, indicating their willingness to support and commit to blockchain implementation when required.

Note to respondents: Response should be based on the organization's overall perception. When necessary, input from Human Resources and functional leaders should be sought for validation.

Score	How is the ATTITUDE AND MOTIVATION OF YOUR COMPANY'S MEMBERS toward blockchain adoption and ORGANIZATIONAL CHANGE?
0	Employees show resistance or indifference toward technological changes. There is no awareness of blockchain or its potential benefits. Discussions about innovation are rare or absent.
1	The organization acknowledges the importance of innovation and technological change. A few employees show curiosity about blockchain, but discussions are informal and sporadic. There is no structured communication or engagement plan, and attitudes toward change vary widely.
2	Employees generally accept technological change, and attitudes toward innovation are positive overall. Blockchain has been introduced in internal communications with clear explanations of potential benefits. The company has initiated basic engagement activities (e.g., informational sessions, Q&A meetings), but empowerment and participation are still limited and not part of a formal change management process.
3	The organization has a formal approach to change management for innovation initiatives. Blockchain is included in structured internal communications, and employees are informed about its potential benefits. Engagement activities (such as workshops or discussion sessions) are organized to prepare staff for possible adoption. Roles and responsibilities for managing change are defined.
4	Employees demonstrate strong motivation and commitment to innovation. Structured programs (e.g., innovation labs, design thinking sessions) empower staff to contribute ideas for blockchain adoption. Leadership actively supports change initiatives and provides incentives for participation. A formal change management plan is documented and ready for execution when adoption occurs.
5	The organization has a deeply embedded culture of innovation and adaptability. Employees are highly motivated and empowered, with formal mechanisms for continuous feedback and participation in blockchain-related initiatives. Change management processes are dynamic and integrated into strategic planning, enabling immediate execution and rapid adjustment to new requirements.

Item 10: Qualified IT team

This item assesses the qualification level of the organization's IT team to support blockchain adoption, either by developing solutions in-house or by translating business needs into clear technical requirements for external providers.

Note to respondents: It is recommended to validate the response with an IT professional. This item is classified under the organizational dimension because it assesses the organization's capability to align IT and business functions and to formalize requirements for blockchain adoption, rather than focusing solely on technical infrastructure.

Score	How QUALIFIED IS YOUR IT TEAM to support blockchain adoption, either through internal development or by translating business needs into requirements for external providers?
0	The IT team has no knowledge of blockchain or related technologies and lacks experience in supporting advanced technology projects or analyzing business processes to specify solutions. IT activities are primarily operational and focused on basic system maintenance.
1	The IT team is aware of blockchain as an emerging technology but has only basic knowledge. They can maintain current IT infrastructure but lack experience in integration projects or blockchain-related discussions.
2	The IT team has experience with general technology projects and understands basic integration concepts. They can communicate general needs about existing systems to external providers (e.g., ERP adjustments, connectivity issues), which could be extended to blockchain. However, translating blockchain-specific requirements remains complex because this requires formalization and deep understanding of both technology and business processes.
3	The IT team has received formal training on blockchain fundamentals and understands the organization's core business processes. They can translate operational needs into technical requirements at a basic level, typically with support from external providers or other functions. However, the team is not yet prepared to independently support or lead blockchain-related initiatives.
4	The IT team possesses specialized knowledge in blockchain platforms, security, and interoperability. They can lead implementation projects, whether through internal development or by managing external vendors, ensuring that complex business requirements (e.g., traceability, compliance, multi-tier inventory management) are accurately reflected in the solution design.
5	The IT team is fully capable of developing, deploying, and maintaining blockchain solutions internally or managing complex vendor relationships with minimal oversight. They have advanced expertise in smart contracts, distributed systems, and security protocols, and can continuously align technical solutions with evolving business needs, enabling immediate execution and rapid adaptation.

Item 11: Awareness of Regulatory Requirements

This item assesses the extent to which the organization is aware of regulatory, legal, and compliance requirements related to the adoption and use of blockchain, including applicable regulations, intellectual property protection, tax-related aspects, and compliance and fraud prevention obligations.

Note to respondents: It is recommended to validate this response with legal and/or compliance professionals (or the responsible function), as it involves the interpretation of regulatory requirements and legal norms.

Score	How AWARE is your company of the REGULATORY, LEGAL, AND COMPLIANCE REQUIREMENTS that must be met for blockchain adoption and use?
0	The company is unaware of any regulations, policies, or legal requirements related to blockchain adoption.
1	The company recognizes that blockchain adoption involves regulatory and legal obligations but has only a general idea. For instance, it knows that privacy laws exist but has not identified which ones apply to its operations.
2	The company has identified some relevant regulations and guidelines, such as data protection laws (e.g., GDPR - General Data Protection Regulation, EU; LGPD – *Lei Geral de Proteção de Dados*, Brazil), as examples, but understands only their basic implications. It does not yet understand how blockchain-specific challenges (such as immutability and traceability) affect compliance with these or other applicable laws.
3	The company has documented the main regulatory requirements that would affect blockchain adoption, including examples like intellectual property protections, anti-fraud measures, and sector-specific compliance rules (e.g., food traceability standards). It understands that these obligations go beyond data protection laws and has assigned responsibilities for monitoring them.
4	The company has a comprehensive understanding of the main regulatory requirements that would affect blockchain adoption. These include privacy and data protection laws (e.g., GDPR, LGPD), compliance obligations, and sector-specific rules. This knowledge is integrated into planning documents, and risk assessments consider legal aspects broadly, without being limited to a single regulation.
5	The company actively monitors changes in laws and regulations that could affect blockchain adoption. It works closely with legal experts and industry associations to stay updated. Internal guidelines are reviewed and updated regularly to ensure compliance with all applicable rules, not just data protection laws. This proactive approach means the company can quickly adapt to new requirements and implement blockchain solutions without delays.

Item 12: Innovation-Oriented Culture

This item assesses the extent to which the organization fosters a culture supportive of innovation, characterized by low risk aversion and openness to new technologies, such as blockchain. It also considers the organization's track record in successfully implementing innovations, reflecting its ability to manage change and translate ideas into effective solutions.

Score	How is the INNOVATION-ORIENTED CULTURE in your company regarding openness to new technologies such as blockchain?
0	The organization has a highly risk-averse culture and resists technological changes. There is no history of innovation initiatives, and employees are not encouraged to propose new ideas.
1	The organization acknowledges the importance of innovation but has no structured initiatives. Occasional improvements occur reactively, and openness to disruptive technologies like blockchain is minimal.
2	The organization has implemented basic innovation practices (e.g., suggestion boxes, informal brainstorming). Some employees show interest in new technologies, but there are no formal process or dedicated resources for innovation.
3	A formal innovation program exists, including structured processes for evaluating new technologies. Blockchain is mentioned in strategic discussions, and the company has documented guidelines for assessing emerging technologies.
4	The organizational culture encourages experimentation and learning, with low risk aversion and recognition for well-conducted initiatives. Blockchain is explored through pilots and proofs of value, and the organization demonstrates the ability to translate experimental outcomes into initial adoption and tangible business improvements.
5	Innovation is embedded in the organizational culture. The company maintains continuous programs for exploring disruptive technologies, including blockchain. There are formal mechanisms for rapid experimentation, partnerships with startups or research institutions, and dynamic processes to adapt the business model to new opportunities.

Item 13: Top management support and governance

This item assesses the level of preparedness and commitment of top management to support blockchain adoption, including the ability to establish appropriate governance mechanisms such as role definition, decision-making protocols, compliance guidelines, and resource planning, ensuring strategic alignment and risk mitigation.

Score	To what extent is your organization's top management committed and prepared to support blockchain adoption and to establish governance mechanisms for this initiative when the time comes?
0	Top management shows no involvement in innovation initiatives or blockchain adoption. There are no governance structures or leadership actions to support technological change.
1	Top management acknowledges the importance of innovation and potential blockchain adoption; however, support remains largely rhetorical. There are no formal actions, assigned responsibilities, or basic guidelines in place to advance or govern such initiatives.
2	Top management demonstrates initial commitment by approving preliminary assessments, vendor demonstrations, or benchmarking activities related to blockchain solutions. Governance practices are informal, and leadership involvement is limited to monitoring progress without active participation.
3	Top management actively participates in planning and decision-making regarding emerging technologies, including potential blockchain initiatives. Governance structures and roles are documented, and limited resources are allocated to controlled assessments, such as proofs of concept, to evaluate feasibility and potential benefits. At this stage, blockchain initiatives remain exploratory and have not yet progressed to an adoption decision.
4	Top management ensures that governance mechanisms are in place to operate once blockchain adoption is decided, including compliance guidelines, risk management practices, and decision-making protocols. Leadership provides effective support by promoting cross-functional coordination, formally approving implementation roadmaps, and ensuring the availability of resources when blockchain adoption is prioritized.
5	Top management maintains governance as a dynamic mechanism integrated into corporate strategy, enabling rapid decision-making and agile adjustments in response to regulatory, technological, or market changes that may affect blockchain adoption. Leadership actively promotes alignment and collaboration across internal functions and relevant partners, ensuring that the organization can scale initiatives consistently and adjust plans and resources efficiently when blockchain adoption is prioritized.

Item 14: Organizational policies and procedures

This item assesses the organization's ability to adapt its policies and procedures to incorporate new standards, routines, and practices required for the future implementation of blockchain, particularly in processes that require traceability and evidence of compliance.

Note to respondents: To provide a more accurate response, validation may be sought from functions responsible for policies and procedures (e.g., quality/process management, compliance/legal, and IT), when necessary.

Score	How adaptable are your ORGANIZATIONAL POLICIES AND PROCEDURES to incorporate changes required for blockchain implementation?
0	Organizational policies and procedures are outdated and focused only on current operations. There is no consideration of emerging technologies or blockchain-related requirements, and no mechanisms exist for revising norms or routines to accommodate technological change.
1	The organization acknowledges that policies and procedures may need adjustments to accommodate emerging technologies, including blockchain, but no formal review or planning has been initiated. Current routines remain unchanged.
2	The organization has begun to identify which policies and procedures may require updates to accommodate emerging technologies, including blockchain. Some adjustments have been made in isolated areas or departments, but these changes are reactive and lack standardization across the organization. There is no formal governance for policy updates, and documentation of changes is inconsistent.
3	Organizational policies and procedures are formally documented, standardized, and recognized as adaptable. There are clear guidelines and mechanisms that allow modifications to accommodate emerging technologies, including blockchain. While these adaptations are not yet comprehensive or proactive, the organization has an established structure to ensure consistency when updates are required.
4	Organizational policies and procedures are fully documented and structured to allow rapid adaptation for emerging technologies, including blockchain. They incorporate flexibility mechanisms and predefined guidelines to ensure that necessary changes can be implemented efficiently when adoption occurs.
5	Policies and procedures are dynamic and continuously updated to accommodate blockchain and other emerging technologies. Automated monitoring and agile governance mechanisms enable rapid adaptation to regulatory, operational, or technological changes.

Item 15: Positive perception toward blockchain

This item assesses the extent to which the organization demonstrates trust in and a favorable perception of blockchain, recognizing and valuing its potential benefits and opportunities for operations.

Score	How POSITIVE IS YOUR ORGANIZATION'S PERCEPTION of blockchain technology and its potential benefits for business operations?
0	The organization has no awareness or understanding of blockchain technology. Members do not recognize its relevance or potential benefits, and there is no discussion about its adoption.
1	The organization is aware of blockchain as an emerging technology but perceives it as distant or irrelevant to its operations. Discussions are informal, and skepticism about its applicability is common.
2	The organization acknowledges that blockchain may offer benefits and has circulated introductory information internally (e.g., articles or brief presentations). Some employees show interest, but perceptions remain mixed, and there is no structured effort to communicate advantages or opportunities.
3	The organization has a generally positive perception of blockchain. Formal communication initiatives (e.g., internal presentations, newsletters) explain their potential benefits for business processes. Employees understand its strategic relevance, and blockchain is considered in discussions about future opportunities.
4	The organization strongly believes in the benefits of blockchain and includes it in strategic planning. Members can clearly identify opportunities for its application in operations, and leadership actively promotes awareness and engagement through structured programs.
5	The organization has a deeply embedded positive perception of blockchain. Employees and leadership share a clear understanding of its value and maintain continuous initiatives to explore new applications. This mindset supports rapid adoption and adaptation when the decision to implement is made.

Item 16: Assessment of financial attractiveness

This item assesses the extent to which the organization is prepared to evaluate the financial attractiveness of blockchain initiatives by applying systematic assessments of costs, risks, and expected returns (e.g., cost–benefit analysis and ROI) to support informed decisions regarding potential future adoption.

Note to respondents: It is recommended to validate this response with finance or controlling professionals (or an equivalent function), as it involves economic evaluation methods and risk assessment.

Score	How capable is your organization of ASSESSING THE FINANCIAL ATTRACTIVENESS of blockchain projects, including risk factors and return on investment?
0	The organization has no processes or tools to evaluate the financial impact of blockchain adoption. Risk factors and potential returns are not considered in decision-making.
1	The organization acknowledges the importance of financial evaluation and applies basic, traditional methods for estimating costs and benefits of investments. However, these assessments are generic and do not address the specific risks or characteristics of emerging technologies such as blockchain.
2	The organization performs financial assessments for investment projects using basic methods such as payback period or simple cost-benefit comparisons. However, these evaluations lack standardized risk analysis and do not use advanced techniques like scenario modeling or sensitivity analysis. Processes are partially documented but not consistently applied.
3	The organization has documented and standardized processes for evaluating investments, including cost-benefit analysis and basic risk identification. These processes are applied consistently and include clear responsibilities. However, they remain focused on traditional projects and do not yet address emerging technologies such as blockchain.
4	Financial evaluation frameworks are fully integrated into strategic planning. The organization uses detailed models to assess costs, risks, and resource requirements for technology adoption projects, and these frameworks are designed to be adapted for emerging technologies such as blockchain.
5	The organization maintains advanced financial assessment capabilities, including dynamic ROI models and scenario simulations for innovation and technology-driven initiatives. Continuous monitoring of market trends and regulatory changes ensures rapid adjustment of financial strategies to support future adoption of emerging technologies, including blockchain.

Item 17: Sustainable Strategy for Blockchain Adoption

This item assesses whether the organization incorporates environmental, social, and economic sustainability principles into its technology adoption strategy, including future blockchain initiatives, by establishing guidelines and mechanisms to evaluate impacts, support responsible decision-making, and ensure long-term viability.

Score	Does your organization include ENVIRONMENTAL, SOCIAL, AND ECONOMIC SUSTAINABILITY PRINCIPLES in its plans for adopting new technologies such as blockchain?
0	The organization does not consider sustainability in technology adoption plans. There are no references to environmental, social, or economic impacts in innovation or investment decisions.
1	Sustainability principles are mentioned in general corporate statements (e.g., mission or values), but they are not connected to technology or innovation projects. Sustainability is not used as a criterion in decisions related to technology adoption.
2	The organization has sustainability-related initiatives (e.g., energy efficiency, waste reduction, or social actions), but they are isolated and not linked to technology adoption. There is no structured approach to consider environmental, social, or economic impacts when planning or evaluating innovation initiatives, including blockchain.
3	Sustainability guidelines are documented and considered during the planning of innovation and technology projects. Responsibilities for addressing environmental, social, and economic aspects are defined, but there are no systematic mechanisms to monitor sustainability indicators or to regularly review and adjust sustainability goals in technology adoption.
4	Sustainability principles are integrated into technology adoption planning. The organization defines and applies sustainability criteria and indicators (e.g., energy consumption, relevant social impacts, and economic feasibility) to guide the evaluation and prioritization of technology projects. Processes are in place to review assumptions and adjust sustainability goals during planning, including when blockchain adoption is considered.
5	The organization maintains a dynamic and continuously reviewed sustainability strategy for technology adoption. Sustainability indicators are regularly monitored and used to update criteria, assumptions, and targets related to technology projects. Decision-making processes enable timely adjustments to ensure that technology adoption initiatives, including blockchain when relevant, remain aligned with environmental, social, and economic sustainability objectives.

Item 18: Business Process Adaptability for Blockchain

This item assesses the organization's capability to document, digitalize, and adapt its business processes, preparing them for future integration with blockchain solutions to support capabilities such as traceability, automation, and interoperability.

Note to respondents: Consider the organization's critical processes (e.g., operations, logistics, procurement, quality, and customer service), particularly those in which traceability and automation can generate value.

Score	How capable is your organization of DOCUMENTING, DIGITIZING, AND ADAPTING ITS CORE BUSINESS PROCESSES to integrate with blockchain-based systems?
0	The organization is not aware of the need to document, digitize, or redesign business processes to enable integration with technologies such as blockchain. Existing processes are not formally documented, and there are no initiatives aimed at their digitization or adaptation. As a result, the organization lacks the capability to adjust processes if blockchain adoption is decided.
1	The organization acknowledges the need to document and redesign business processes to support future technology integration, including blockchain. Initial discussions have taken place regarding workflow improvements and the reduction of manual activities; however, no structured plan currently exists.
2	Some processes are documented and partially digitized using basic tools such as spreadsheets, task management platforms, or simple ERP modules. Adaptations for technology integration occur reactively and in isolated areas. There is no formal methodology for process redesign or alignment with emerging technologies.
3	Core business processes are documented, standardized, and mapped in detail. The organization has established guidelines for process redesign and digitization to support innovation projects. However, these practices are generic and not yet tailored for blockchain requirements such as traceability or immutability.
4	Core business processes are largely digitized and integrated into corporate systems, reducing reliance on manual records. The organization can adapt workflows to increase interoperability and automation, and it already considers typical requirements that would be needed for a potential blockchain integration (e.g., consistent traceability, data standardization, and record integrity). Once adoption is decided, processes can be adjusted efficiently to support more advanced technological integration
5	The organization maintains dynamic, continuously improving business processes with the ability to be rapidly reconfigured in response to new partner, regulatory, or technological requirements. Automation and integration across processes and systems are sufficiently flexible to accommodate blockchain-based solutions when prioritized.

Item 19: Strategic Adaptability of the Business Model

This item assesses the organization’s ability to strategically adjust its business model, including its value proposition, revenue generation, and partnerships, to leverage opportunities associated with the future use of blockchain, such as reduced intermediation, increased transparency, and new service offerings.

Score	How capable is your organization of ADAPTING ITS BUSINESS MODEL (value proposition, revenue streams, partnerships) to leverage opportunities offered by blockchain?
0	The organization has a rigid business model with no consideration of adjustments for emerging technologies. Value proposition, revenue streams, and partnerships remain unchanged.
1	The organization acknowledges that technological changes may require adjustments to the business model. Initial conversations occur, but there is no structured analysis of blockchain’s potential impact on value creation or partnerships.
2	Preliminary assessments of the business model exist, such as benchmarking competitors or identifying areas for digital improvement. Some opportunities (e.g., new service channels) are noted, but initiatives are isolated and not linked to a formal strategy for disruptive technologies like blockchain.
3	The organization has documented guidelines for reviewing and adjusting the business model. Blockchain is included in strategic discussions, and potential impacts on value proposition, revenue streams, and partnerships are analyzed. However, there are no detailed implementation plans or resource allocation.
4	The organization integrates business model adaptability into strategic planning, using scenarios and action plans to address potential changes in value proposition, revenue generation, and partnerships if blockchain adoption is prioritized. Alternative repositioning options (e.g., new services, new monetization approaches, or adjustments to the role of intermediaries and partners, when applicable) are defined and ready for execution following an adoption decision.
5	The organization maintains a dynamic business model with the ability to be rapidly reconfigured to capture blockchain-related opportunities once adoption is decided. The organization continuously monitors trends and evaluates opportunities, enabling agile adjustments to value propositions, revenue streams, and partnership arrangements without requiring major restructuring, thus supporting rapid response to market and external requirements.

EXTERNAL ENVIRONMENT DIMENSION

Recommended respondent: supply chain manager, operations manager, commercial manager, or equivalent role with partner-facing responsibility.

This form assesses an organization’s external-environment readiness (supply chain dimension) for blockchain adoption.

This questionnaire is part of a broader blockchain adoption readiness instrument structured into three dimensions: Technological, Organizational, and External Environment (Supply Chain). This module includes only Items 20–26. Please answer based on the organization’s current situation.

Item 20: Compliance between Supply Chain partners

This item assesses the degree of compliance among supply chain partners with respect to laws, industry regulations, and shared ethical standards, as well as the alignment of objectives that strengthens trust, reduces conflicts, and protects intellectual property, thereby creating favorable conditions for future integration with blockchain solutions.

Note to respondents: When necessary, this item may be validated with functions such as Procurement/Purchasing, Quality, Legal/Compliance, and/or Partner Management.

Score	To what extent do your supply chain partners comply with regulations, ethical standards, and collaborative agreements to ensure trust and alignment for future blockchain integration?
0	There is no formal compliance framework among supply chain partners. Interactions are based on informal agreements, and adherence to regulations or ethical standards is not monitored.
1	The organization acknowledges the importance of compliance but relies on basic contractual clauses without verification mechanisms. Discussions about aligning standards across partners are informal and sporadic.
2	Compliance requirements are documented in contracts, and partners are expected to follow external regulations and internal policies. For example, agreements may include clauses on anti-corruption practices, data protection (e.g., LGPD/GDPR), and product quality standards. However, monitoring is limited to occasional checks, and enforcement mechanisms are weak, leading to inconsistencies.
3	The organization has formal compliance guidelines for supply chain partners, including ethical standards, intellectual property protection, and adherence to sector-specific regulations (e.g., food traceability, chemical safety). Roles and responsibilities for monitoring compliance are assigned, and periodic audits or compliance assessments are conducted, but processes are still manual and fragmented.
4	Compliance adaptability is integrated into supply chain governance. Standardized procedures are in place to verify adherence and implement adjustments (e.g., structured audits, certifications when applicable, and controlled protocols for sharing compliance evidence). Supply chain partners are able to respond more quickly and consistently to new regulatory and ethical requirements, strengthening trust and alignment across the supply chain.
5	The organization and its supply chain partners maintain dynamic compliance systems with real-time monitoring and automated verification processes. For example, digital compliance dashboards, automated alerts for non-conformities, and shared platforms for audit records are in place. These capabilities are designed to integrate seamlessly with blockchain for immutable and auditable compliance tracking.

Item 21: Digital Infrastructure for Supply Chain Connectivity

This item assesses the capability of supply chain partners to maintain adequate digital infrastructure to ensure seamless connectivity and real-time information exchange across the value chain, creating favorable conditions for future integration with blockchain solutions.

Note to respondents: Consider the organization's critical partners (e.g., those with higher volume, risk, or operational impact).

Score	How adequate is the digital infrastructure across your supply chain ecosystem to enable real-time information exchange and seamless connectivity among partners?
0	Supply chain partners lack digital infrastructure for connectivity. Information exchange is manual or paper-based, with no integration between systems.
1	Basic digital tools (e.g., email and spreadsheets) are used for communication among partners, but without structured integration. Data sharing is slow, relies heavily on manual intervention, and is prone to errors and rework.
2	Some partners use dedicated platforms (e.g., ERP or EDI systems) for data exchange, but integration is limited and fragmented. Real-time connectivity is not possible, and processes rely on periodic updates.
3	The digital infrastructure is standardized across key partners, enabling structured and secure data exchange. Real-time connectivity is in place for selected processes (e.g., orders and traceability), and interoperability requirements (data exchange standards and integration specifications) are documented.
4	The digital infrastructure supports automated, real-time data exchange with most relevant partners. API-based integrations and secure protocols are implemented, and systems are prepared to accommodate advanced interoperability and, where applicable, future connectivity with blockchain-based solutions (e.g., nodes, services, and integration standards).
5	The supply chain ecosystem maintains a fully interoperable digital infrastructure with dynamic integration across partners and automated real-time connectivity in critical flows. The ecosystem can scale (e.g., additional partners, higher data and transaction volumes) without significant performance loss or the need for extensive restructuring. Platforms and integrations can adapt rapidly to evolving requirements and changes over time, including those associated with blockchain adoption, with low reconfiguration effort.

Item 22: Supply Chain innovation culture

This item assesses the extent to which supply chain partners demonstrate a culture supportive of innovation and low risk aversion, thereby increasing collective readiness to adopt emerging technologies such as blockchain.

Note to respondents: Responses should consider the organization's critical partners (e.g., those with higher operational impact, volume, or risk).

Score	How strong is the culture of innovation among your supply chain partners, in terms of openness to new technologies and willingness to adopt disruptive solutions like blockchain?
0	Supply chain partners show high risk aversion and resistance to technological change. There is no history of collaborative innovation initiatives.
1	Partners acknowledge the importance of innovation but have only informal discussions. Adoption of new technologies is rare and occurs reactively.
2	Some partners participate in isolated innovation projects or pilot programs, but collaboration is limited. There is no structured approach to foster openness to disruptive technologies.
3	Innovation is part of the supply chain strategy. Partners have documented guidelines for evaluating new technologies and participate in joint initiatives, though adoption remains cautious.
4	Supply chain partners actively collaborate on structured innovation programs and joint pilot projects for emerging technologies. Formal mechanisms exist for sharing resources, knowledge, and risk (e.g., co-investment agreements, joint R&D initiatives). Blockchain is included in strategic roadmaps, and partners have defined preliminary technical requirements and governance models to enable integration when adoption occurs.
5	The supply chain ecosystem operates with a deeply embedded innovation culture and dynamic collaboration. Partners actively participate in industry consortia and innovation hubs to define standards and explore blockchain opportunities. Flexible agreements and joint investment strategies are in place to enable rapid onboarding when adoption is decided. Continuous monitoring of market trends and co-development initiatives for emerging technologies ensure the ecosystem can immediately adapt to blockchain integration without major restructuring.

Item 23: Relationship with blockchain solutions providers

This item assesses the organization's ability to establish and maintain effective relationships with blockchain solution providers, enabling collaboration, access to technical support, and the development of solutions aligned with organizational needs when adoption is pursued.

Score	How prepared is your organization to build and maintain strong relationships with blockchain solution providers for future collaboration and tailored solutions?
0	The organization has no contact or engagement with blockchain solution providers. There is no awareness of potential vendors or technical assistance options.
1	The organization acknowledges the need for external expertise and has identified potential providers informally. However, there are no established communication channels or preliminary discussions.
2	Initial contacts with blockchain solution providers exist, and the organization has gathered basic information about services and capabilities. Engagement is limited to exploratory conversations without formal agreements or collaboration plans.
3	The organization has established formal communication channels and documented guidelines for selecting and engaging blockchain solution providers. Preliminary collaboration frameworks are in place, and technical requirements have been shared for future solution development.
4	The organization maintains structured relationships with selected providers, supported by preliminary collaboration agreements or documented engagement plans for future projects. Technical assistance arrangements and initial solution concepts tailored to organizational needs are defined, ensuring readiness to move forward when adoption is decided.
5	The organization has strategic partnerships with blockchain solution providers, including flexible agreements and joint planning mechanisms that enable rapid onboarding when adoption is decided. Providers are actively involved in co-designing potential solutions, and the organization participates in vendor-led innovation programs to ensure alignment with emerging standards and technologies.

Item 24: Relationship with Customers

This item assesses the organization's ability to maintain strong relationships and effective communication with its customers, enabling direct, timely, and, where applicable, automated information exchange, thereby creating a favorable foundation for engagement and collaboration in future blockchain initiatives.

Score	How strong and collaborative is your organization's relationship with its customers, fostering trust and long-term engagement?
0	Customer relationships are purely transactional, focused only on immediate sales or service delivery. There is no trust-based partnership or collaborative engagement.
1	The organization acknowledges the importance of stronger customer relationships and has begun informal efforts to improve communication. Collaboration is minimal, and interactions remain reactive.
2	Regular communication channels exist, and the organization engages customers in basic collaborative activities (e.g., feedback collection, periodic meetings). However, relationships are still limited to operational needs.
3	Customer relationships are structured and based on trust and long-term collaboration. Formal mechanisms for engagement exist (e.g., joint planning sessions, service-level agreements), and customers are involved in discussions about process improvements.
4	The organization maintains strong, partnership-oriented relationships with customers, including joint initiatives for innovation and continuous improvement. Customers demonstrate openness to future technology integration, and collaboration extends beyond transactional exchanges.
5	Customer relationships are strategic and deeply collaborative, with co-development of solutions and shared innovation programs. There is mutual trust and alignment on digital transformation goals, ensuring readiness for rapid adoption of blockchain-based engagement when decided.

Item 25: Relationship with Suppliers

This item assesses the organization's ability to maintain strong relationships and effective communication with its suppliers, enabling direct, timely, and automated information exchange, thereby creating a favorable foundation for future collaboration through technologies such as blockchain.

Score	How strong and collaborative is your organization's relationship with its suppliers, fostering trust, alignment, and long-term partnership?
0	Supplier relationships are purely transactional, focused only on price and delivery. There is no trust-based partnership or collaborative engagement.
1	The organization acknowledges the importance of stronger supplier relationships and has begun informal efforts to improve communication. Collaboration is minimal, and interactions remain reactive.
2	Regular communication channels exist, and the organization engages suppliers in basic collaborative activities (e.g., performance reviews, periodic meetings). However, relationships are still limited to operational needs.
3	Supplier relationships are structured and based on trust and long-term collaboration. Formal mechanisms for engagement exist (e.g., joint planning sessions, shared quality improvement initiatives), and suppliers are involved in discussions about process optimization.
4	The organization maintains strong, partnership-oriented relationships with suppliers, including joint initiatives for innovation and continuous improvement. Suppliers demonstrate openness to future technology integration, and collaboration extends beyond transactional exchanges to strategic alignment.
5	Supplier relationships are strategic and deeply collaborative, with co-development of solutions and participation in shared innovation programs. There is mutual trust and alignment on digital transformation goals, ensuring readiness for rapid adoption of blockchain-based collaboration when decided.

Item 26: Transparency among supply chain actors

This item assesses the level of transparency and mutual trust among supply chain actors, as reflected in collaborative practices and information sharing that strengthen the ecosystem and create favorable conditions for future integration with blockchain-enabled solutions.

Score	How strong is the level of transparency and trust among your supply chain partners, enabling open information sharing and collaborative decision-making?
0	There is no established practice or expectation of transparency among partners. Information is not proactively shared, exchanges are manual and ad hoc, and partners do not agree on what to share, when, or how. Trust is low and disputes over data accuracy, timeliness, and responsibilities are frequent.
1	Partners recognize the importance of transparency and begin to respond to information requests, but sharing occurs only upon demand or contractual obligation. Communication is reactive, channels are informal (e.g., emails without standard templates), and there are no agreed data standards; however, there is a minimum willingness to cooperate when asked.
2	Basic transparency practices exist, such as sharing operational data for logistics or compliance purposes. However, data exchange is selective, often delayed, and trust remains moderate. There are no formal mechanisms for validating shared information.
3	Transparency is structured through formal agreements and standardized reporting formats. Partners share operational and compliance data regularly, and trust is reinforced by documented processes and periodic reviews. However, integration is still manual or semi-automated.
4	Supply chain partners maintain strong transparency practices, including proactive sharing of performance, compliance, and traceability data. Secure digital channels and agreed protocols are in place, and partners collaborate on governance models to ensure data integrity for future blockchain integration.
5	Transparency is embedded in the supply chain culture. Partners share real-time data through interoperable platforms, supported by automated validation and audit trails. Collaborative governance structures exist, and partners align on digital transformation goals, ensuring readiness for rapid adoption of blockchain-based transparency solutions when decided.

INSTRUMENT ACCEPTANCE ASSESSMENT
(QUESTIONNAIRE EVALUATION)

We are now assessing your perception of this questionnaire.

Item A — Perceived Usefulness of the Questionnaire

This questionnaire is useful for assessing the organization’s readiness for blockchain adoption and for supporting action planning.

( ) Strongly disagree
( ) Disagree
( ) Slightly disagree
( ) Slightly agree
( ) Agree
( ) Strongly agree

Item B — Ease of Use of the Questionnaire

This questionnaire is easy to complete (clear items and response options that do not require excessive effort).

( ) Strongly disagree
( ) Disagree
( ) Slightly disagree
( ) Slightly agree
( ) Agree
( ) Strongly agree

Item C — Suggestions for Improvement

Do you have any suggestions for improving this questionnaire (e.g., terminology, clarity, response options, missing items, or redundancies)?

____

____

____

____

Respondent Profile (For Internal Research Use Only)

What is your primary area of work?

( ) IT / Information Systems

( ) Innovation / Digital Transformation

( ) Supply Chain / Operations / Logistics

( ) Purchasing / Procurement

( ) Quality / Certifications

( ) Finance / Controlling

( ) Legal / Compliance

( ) Human Resources / People Management

( ) Sales / Customer Relations

2. Current position / role

____

3. Your role in the organization is mainly:

( ) Strategic (decision-making / direction)

( ) Tactical (management / coordination)

( ) Operational (execution)

( ) Advisory / consulting

( ) Prefer not to answer

4. How long have you worked in this area (in your career)?

( ) Less than 1 year

( ) 1–3 years

( ) 4–7 years

( ) 8–15 years

( ) More than 15 years

5. How long have you worked at this organization?

( ) Less than 1 year

( ) 1–3 years

( ) 4–7 years

(   ) 8–15 years

(   ) More than 15 years

(   ) Prefer not to answer

APPENDIX D – Fuzzy Rule Base

Below we report the final set of 27 fuzzy rules resulting from expert-based refinement. These rules were implemented in the fuzzy inference engine.

Rule	Technological	Organizational	External Environment	Readiness
R01	Basic	Initial	Reactive	Very Low
R02	Basic	Initial	Collaborative	Very Low
R03	Basic	Defined	Reactive	Very Low
R04	Integrated	Initial	Reactive	Very Low
R05	Basic	Optimizing	Reactive	Low
R06	Advanced	Initial	Reactive	Low
R07	Basic	Initial	Orchestrated	Low
R08	Basic	Defined	Collaborative	Low
R09	Basic	Defined	Orchestrated	Low
R10	Basic	Optimizing	Collaborative	Low
R11	Basic	Optimizing	Orchestrated	Low
R12	Integrated	Initial	Collaborative	Low
R13	Integrated	Defined	Reactive	Low
*R14**	*Integrated*	*Initial*	*Orchestrated*	*Low*
*R15**	*Advanced*	*Initial*	*Collaborative*	*Low*
R16	Integrated	Optimizing	Reactive	Medium
R17	Advanced	Defined	Reactive	Medium
R18	Advanced	Optimizing	Reactive	Medium
R19	Advanced	Initial	Orchestrated	Medium
R20	Advanced	Defined	Collaborative	Medium
R21	Integrated	Defined	Collaborative	Medium
R22	Integrated	Optimizing	Collaborative	Medium
R23	Integrated	Defined	Orchestrated	Medium
*R24**	*Integrated*	*Optimizing*	*Orchestrated*	*High*
R25	Advanced	Defined	Orchestrated	High
R26	Advanced	Optimizing	Collaborative	High
R27	Advanced	Optimizing	Orchestrated	Very High

**Rules whose consequent were revised after the expert panel.*

APPENDIX E – Proposed Technological Products

E1. Blockchain Adoption Readiness Assessment Platform

This appendix outlines a proposal for a technological product derived from the readiness model developed in this thesis. The proposed solution consists of a digital platform designed to support organizations in assessing their readiness for blockchain adoption in supply chain networks.

The platform would function as an interactive web-based portal in which companies can register and complete a structured readiness assessment based on the dimensions and conditions defined in the proposed model. The assessment would be implemented through a questionnaire aligned with the readiness construct, allowing respondents from different functional areas to provide input on technological, organizational, external environment dimensions.

Once the assessment is completed, the system would automatically generate a diagnostic report for the participating organization. This report would include the global readiness classification, dimension-level scores, and a visual representation of strengths and weaknesses. In addition, the platform could provide tailored recommendations highlighting critical areas that require improvement before blockchain adoption is pursued.

Beyond individual assessments, the platform would also enable the aggregation of anonymized data across participating organizations. This would allow the generation of benchmarking reports, in which companies can compare their readiness levels against industry averages, firm size categories, or supply chain positions. This functionality would provide valuable insights into how readiness varies across sectors, organizational profiles, and supply chain configurations.

From a research perspective, the platform would also serve as a continuous data collection mechanism, enabling the refinement of the readiness model over time and supporting future studies on blockchain adoption and digital transformation in supply chain contexts. From a managerial perspective, the proposed tool would provide a practical, user-friendly, and scalable solution for supporting informed decision-making related to blockchain adoption.

Overall, this technological product operationalizes the main contribution of this thesis by translating the readiness model into a digital decision-support tool that bridges academic research and organizational practice.

E2. Application Manual for the Blockchain Adoption Readiness Model

In addition to the proposed digital platform, a second complementary technological product consists of a structured application manual for the readiness assessment model developed in this thesis.

The purpose of this manual is to provide organizations, consultants, and practitioners with clear guidance on how to apply the readiness model in practice, independently of the digital platform. The manual would include step-by-step instructions on how to conduct the assessment, identify appropriate respondents, and interpret the results.

Specifically, the manual would define the scope of the assessment, describe the meaning of each readiness dimension and item, and provide guidance on how to collect reliable responses across different organizational areas. It would also present the logic used to synthesize the results into an overall readiness classification, ensuring transparency in the assessment process.

In addition, the manual could include illustrative examples and application scenarios to support understanding, as well as recommendations on how organizations can use the results to guide decision-making, prioritize improvement initiatives, and avoid premature blockchain implementation.

By complementing the digital platform, the manual ensures that the readiness model remains accessible and applicable across different organizational settings and modes of application. Together, these two products extend the practical impact of the thesis by enabling both structured application and scalable deployment of the proposed readiness assessment approach.

ANNEX A – Emerald Publishing Author Rights Policy for Paper 1

This annex presents the Emerald Publishing author rights policy consulted to verify the conditions for including Paper 1 in this thesis. According to the policy, authors may include their work in a dissertation or thesis; however, when electronic deposit is required, the Submitted Manuscript Under Review (SMUR) or the Author Accepted Manuscript (AAM) version must be used instead of the Version of Record (VoR).

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I have the...	Submitted version under review (SMUR)	Author accepted manuscript (AAM)	Version of record (VoR) or Publisher PDF	Gold Open Access Version of Record
I want to...				
Use my article or book chapter for teaching and classroom purposes	Unlimited print copies Electronic use permitted within faculty only			
Make photocopies of my article or book chapter for conferences, or to use as handouts	Unlimited		Up to 25 copies. If you require more, please see Marketplace	
Include my article or book chapter in my dissertation or thesis	Yes	Yes	The VoR may be included in the print version of your thesis/dissertation. If an electronic deposit is required, this must be the SMUR or AAM version	
Reuse figures or extracts in other works authored by me	Yes	Yes	Yes	
Republish the entirety of my work in any future works	You may republish your Emerald work in a book, where your name appears on the front cover as editor or author, subject to certain conditions. Please see Marketplace for further details.			
Deposit my article or book chapter in my institutional repository	Anytime	Upon official publication	No. You may include the metadata of your work, and provide the digital object identifier (DOI) to the version of record on Emerald Insight	Can share at any time in accordance with Creative Commons licence (see below)
Post my article or book chapter on my personal or corporate website, or relevant not-for-profit subject repository	Anytime	Upon official publication	No. You may include the metadata of your work, and provide the digital object identifier (DOI) to the version of record	
Upload my article or book chapter to a scholarly collaboration network	Anytime, but only if the site is a signatory of the STM article sharing principles	Upon official publication. Only if the site is a signatory of the STM article sharing principles	No. You may include the metadata of your work, and provide the digital object identifier (DOI) to the version of record, or the link to a version deposited into your institutional repository	
Email my article or book chapter to colleagues	Anytime, to individuals for person use only			
Post my article or book chapter on social media	No. You may include the metadata of your work, and provide the DOI to the version of record, or the link to a version deposited into your institutional repository			
Include my work as part of a grant or funding application	Anytime			